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CONCEPTS FOR ICEBREAKER WITH INTEGRAL AIR CUSHION BOW

for the

TRANSPORTATION DEVELOPMENT CENTRE
TRANSPORT CANADA

by

CANFIN ARCTIC CONSULTANTS LTD.
Pointe Claire, Quebec

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17. Abstract

Theoretical developments are carried out on the dimensions, the pressure and the power required for an air cushion used for icebreaking, and on the force transfer from cushion to ship as ice is broken.

The effect of introducing an air cushion on an icebreaker is achieved by removing, in the resistance formula, the term associated with ice cover rupture.

A parametric study is carried out, based on the modified resistance formula to find out the influence of the bow shape, the ship beam and the ice thickness on the power requirement for propulsion and for the air cushion.

Results are compared to those of conventional icebreakers. Different concepts of integrated air cushion platforms are also discussed.

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17. Résume

Une analyse est effectuée sur les dimensions, la pression et la puissance requises pour un coussin d'air utilisé pour briser la glace, et sur les forces transmises par le coussin à la structure du navire lors de la rupture.

On modifie l'algorithme de résistance du brise-glace en enlevant le terme associé à la rupture du couvert de glace pour tenir compte de l'effet du coussin d'air. On effectue ensuite une étude paramétrique afin de trouver l'influence de la forme de l'étrave, de la largeur du navire et de l'épaisseur de la glace sur la puissance requise pour la propulsion et pour le coussin d'air.

Les résultats sont comparés à ceux obtenus pour un brise-glace conventionnel. Divers concepts d'intégration du coussin d'air sont aussi discutés.

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LIST OF SYMBOLS

For the convenience of the reader the symbols have also been explained in the text when they appear for the first time.

SI units are used in all formulas.

B	=	breadth of ship, m
B_{AC}	=	breadth of air cushion platform, m
c	=	damping coefficient
c_c	=	critical damping coefficient
c_D	=	drag coefficient, loss coefficient
e	=	the base of the natural logarithm, 2.7183
F	=	vertical force, kN
G	=	estimated weight of air cushion platform, kN
g	=	gravitational constant, 9.81 m/s^2
h	=	thickness of level ice, m
Δh	=	distance between under surface of ice and bottom of cavity, m
h_c	=	pressure head of cushion pressure, m
L	=	waterline length of ship, m
L_{min}	=	minimum length of air cushion platform, m
l	=	length of unsupported ice, m
l_c	=	perimeter of air cushion platform skirt, m
m	=	mass, kg
P_{AC}	=	power of air cushion platform, kW
P_S	=	power on shaft of ship, kW
ΔP	=	power difference, kW
p	=	pressure, Pa, kPa
Δp	=	pressure difference
p_{DYN}	=	dynamical pressure, Pa
p_c	=	cushion pressure, Pa, kPa

R_{AC} = resistance of air cushion, kN
R_{ICE} = ice resistance, kN
R_b = breaking resistance, kN
R_S = submersion resistance, kN
R_V = velocity resistance, kN
T_o = bollard pull of ship, kN
T(v) = tow rope pull (= propeller net thrust minus open water resistance), kN
t = time
v = speed, m/s
Δv = speed difference, m/s
v_{ow} = maximum open water speed, m/s
z = vertical coordinate (see section 2.2), m
$\dot{z}$ = speed, m/s
$\ddot{z}$ = vertical acceleration, m/s^2
Δ = displacement of ship, tons
η = total efficiency of fan(s)
ζ = $\frac{c}{c_c}$, damping/critical damping
ρ_A = density of air, kg/m^3
ρ_i = density of ice, kg/m^3
ρ_w = density of water, kg/m^3
σ_b = bending stress of ice, Pa, kPa
φ = $\tan^{-1}\sqrt{\frac{1}{\zeta^2} - 1}$
ω_n = natural frequency, 1/s
ω_d = damped natural frequency, 1/s

1 INTRODUCTION

The level ice resistance encountered by ships operating in the continuous mode consists of three components:

- Breaking resistance.

  This component is due to the breaking process at the bow of a ship. The ice crushes against the shell plating until the vertical force component acting through the contact area is big enough to break a cusp from the ice field. Close to the stem of a conventional bow the ice is continuously crushed as the ship proceeds.

- Submersion resistance.

  This component is due to the submersion of the broken ice floes.

- Velocity resistance.

  This component is caused by the acceleration of the broken ice floes.

Thus the total ice resistance, which is the sum of the three components, can be written:

$$R_{ICE} = R_{\zeta} + R_S + R_V$$

Under certain conditions an air cushion vehicle will be able to break level ice. Consequently, the breaking component R_{ζ} is deleted when an icebreaking air cushion platform is used in front of a ship. Instead the air cushion platform has a resistance R_{AC}. Thus the total ice resistance of the ship - air cushion combination is

$$R_{ICE} = R_{\zeta} + R_{AC}$$

This is schematically shown in Fig. 1. If the ship speed is kept constant we get a reduction in propulsion power of the ship

$$\Delta P = POWER_1 - POWER_2$$

On the other hand, if we keep the propulsion power constant we get an increase of the ship speed by Δv.

The breaking of level ice by the air cushion method is feasible when

$$\Delta P > P_{AC}$$

where P_{AC} is the power of the air cushion platform required to create a big enough cavity under the ice cover to break the ice.

Some examples of the relation between the resistance components are shown in Figure 2.

The required air cushion power is determined mainly by:

- Ice thickness, which is proportional to the cushion pressure.
- Perimeter of the air cushion. The air leakage under the skirts is proportional to the perimeter of the air cushion.
- Ice properties, which determine the maximum dimensions of an unsupported ice cover. This gives the minimum size of the air cushion needed to break ice of a certain thickness.

The facts discussed above imply the use of an air cushion vehicle attached in front of a ship in order to improve the capability of the ship to operate in ice. However, the combination of a separate air cushion vehicle to a ship involves some disadvantages:

- Problems with the connection between the ship and air cushion platform
- The air cushion platform in front of the ship hampers the operation in other ice conditions, e.g. in ice ridges
- Risks for damages when operating in open water, e.g. during transits from one area of operation to another.

The purpose of this study was to establish a concept which exploits the positive effect of an air cushion on the operation of ships in level ice and simultaneously minimizes the disadvantages listed above, and to make a preliminary feasibility study of the chosen concept. This study was made under DSS Contract No. OSD81-00052 of July 27, 1981.

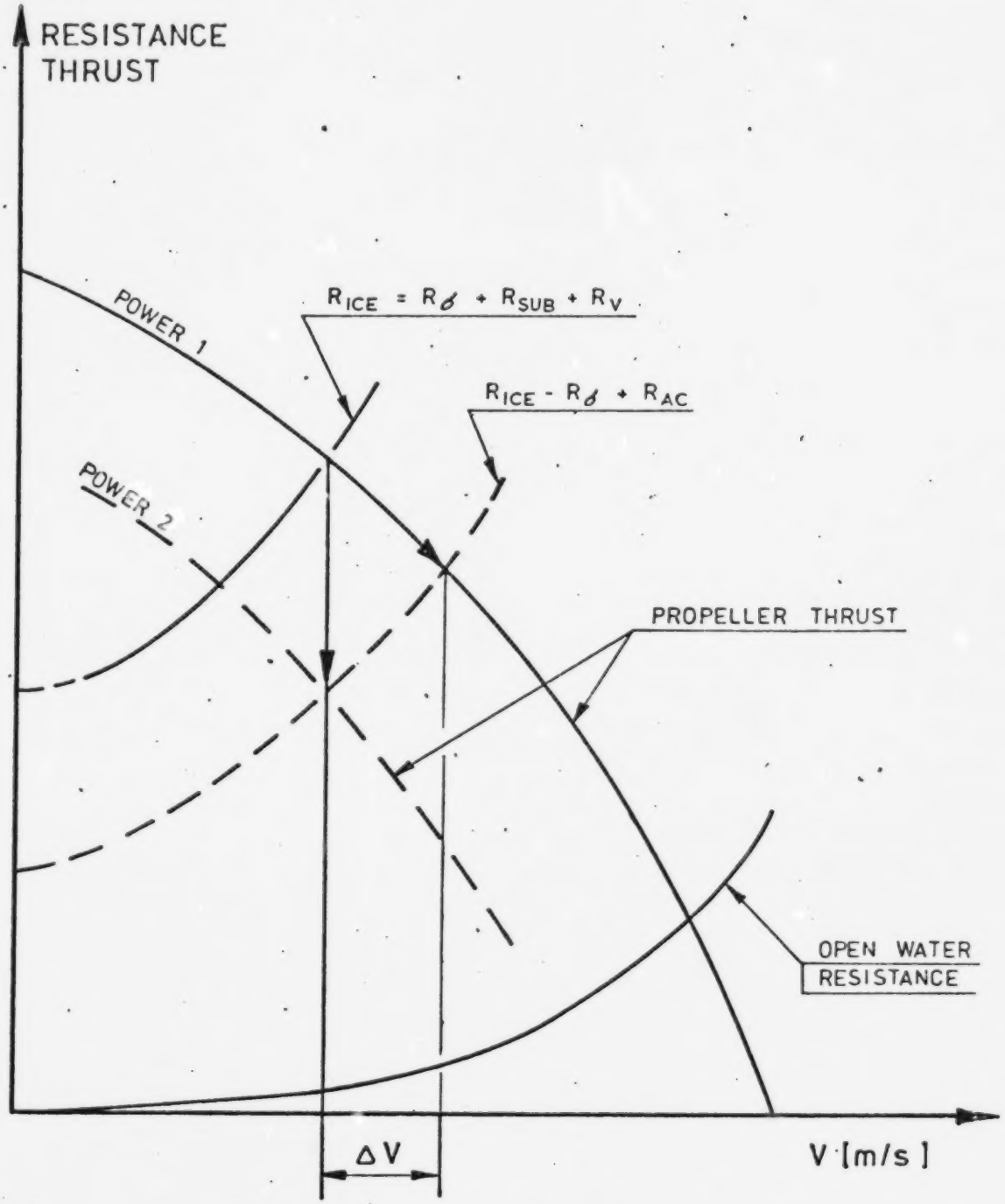


Figure 1 Schematic drawing of propeller thrust and resistance.

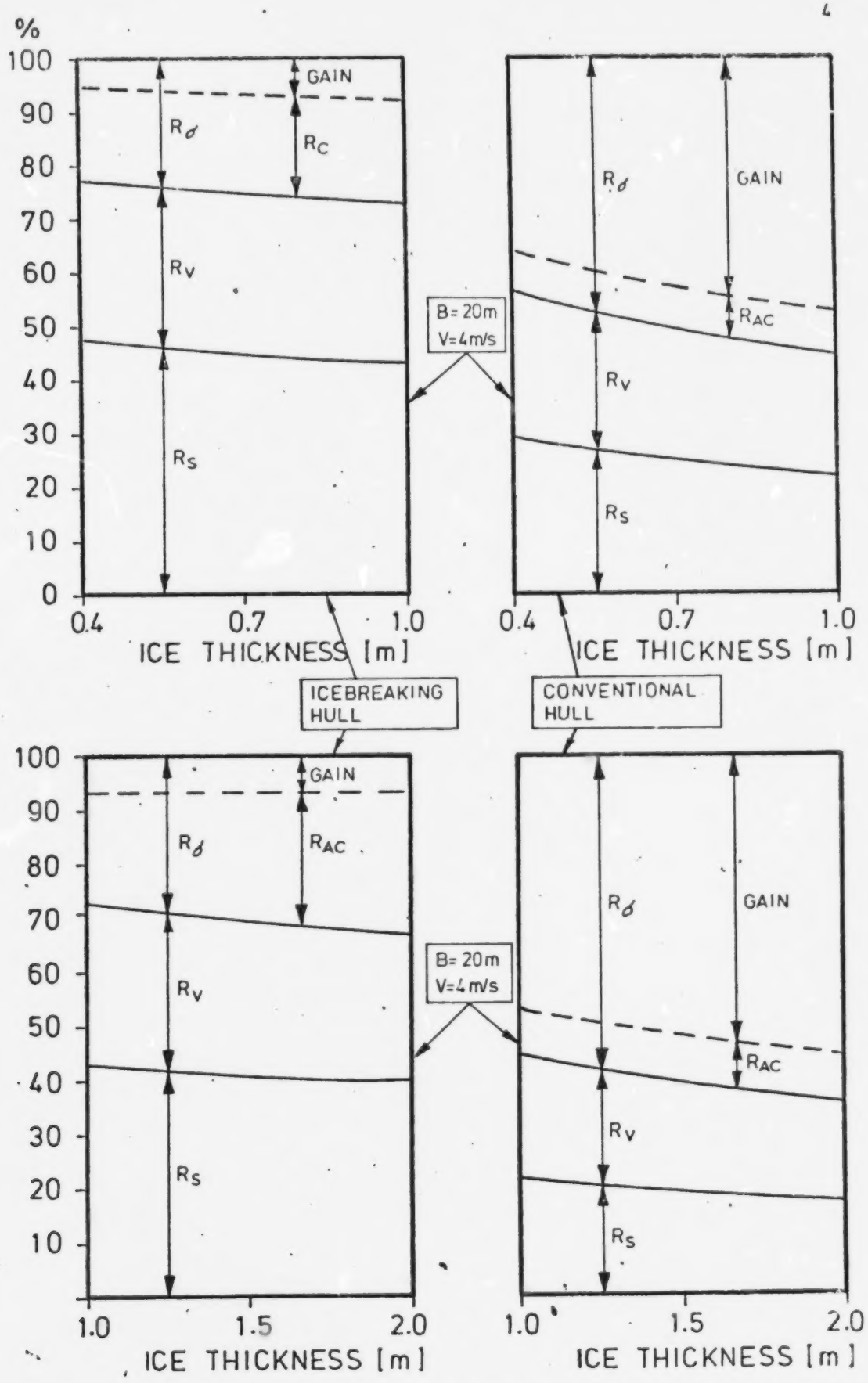


Figure 2 Relation between ice resistance components.

2 BASIC THEORY OF BREAKING LEVEL ICE AT LOW SPEED WITH A SHIP - AIR CUSHION COMBINATION

2.1 LEVEL ICE RESISTANCE AND PROPULSION POWER

As mentioned in Chapter 1, the ice resistance of a ship is divided into components in the following way:

$$R_{ICE} = R_b + R_S + R_V$$

The components have been investigated both in the icebreaking laboratory and with ships. Figs. 3 and 4.

When calculating the ice resistance of a ship - air cushion platform combination the formula is

$$R_{ICE} = R_S + R_V + R_{AC}$$

The resistance, R_{AC}, of the air cushion platform when breaking ice, is at low speeds approximately:

$$R_{AC} = B_{AC} \cdot h_c \cdot p_c$$

where

B_{AC} = breadth of air cushion

h_c = pressure head of cushion pressure

p_c = cushion pressure

This formula is based on the assumption that the aft skirt reaches the bottom of the cavity and the front skirt the unbroken ice (Fig. 5). The resistance is obtained by multiplying the front area of the cavity by the cushion pressure. The friction between the skirt segments and the ice and water has been neglected as it is known from resistance tests on level ice and water that this friction force is very small compared to the total resistance of the ship - air cushion combination.

In addition to the ice resistance formulas discussed above, the following approximative formulas have been used for determining the capability of a ship and a ship - air cushion combination to operate in level ice:

The maximum speed in open water has been calculated as

$$v_{ow} = 1.994 \frac{\sqrt[3]{P_s}}{\sqrt[6]{\Delta}}, \text{ (m/s)}$$

where

P_s = shaft power (kW)

Δ = displacement (ton)

The tow rope pull between zero and full speed is assumed to follow the formula:

$$T(v) = T_o \left(1 - \frac{1}{3} \frac{v}{v_{ow}} - \frac{2}{3} \left(\frac{v}{v_{ow}} \right)^2 \right)$$

where the bollard pull T_o has been taken as

$$T_o \text{ (kN)} = 0.12 \ P_s \text{ (kW)}$$

Fig. 3. Icebreaking tests with a ship. The aim of these specific tests is to investigate ice resistance components. The breaking is eliminated by pre-sawing the ice.

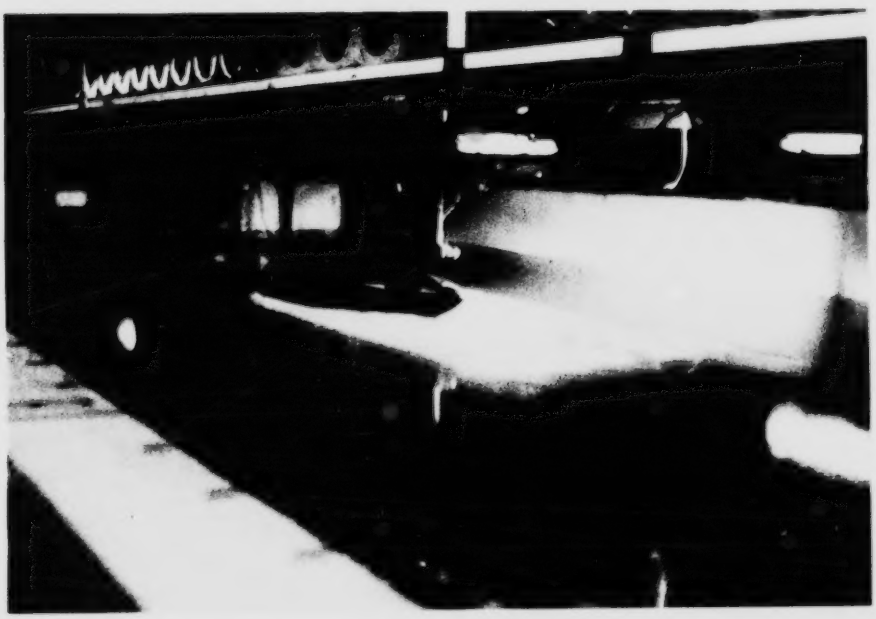
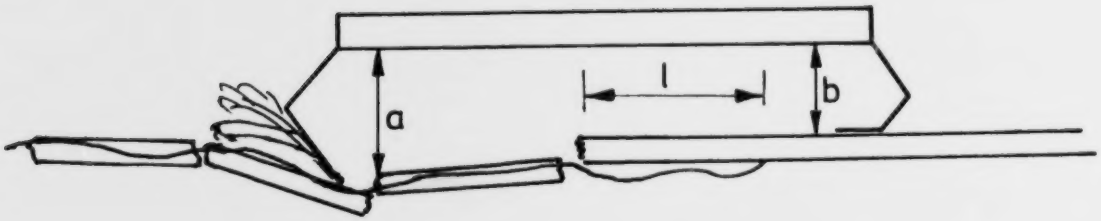


Fig. 4. Investigation of ice resistance components in the icebreaking laboratory.



$$a - b = h_c$$

Figure 5 Principle of low-speed icebreaking.

2.2 REQUIREMENTS ON THE SIZE OF THE AIR CUSHION PLATFORM FOR BREAKING LEVEL ICE AT LOW SPEED

The maximum vertical force on the ice is the weight of the ice (Fig. 6). The circumferential stresses in the ice, created by the weight of the ice, will first initiate radial failures in the ice, which means that the unsupported ice can be considered as beams. Simple beam theory gives the maximum length l of the unsupported beams.

$$l = \sqrt{\frac{\sigma_b h}{\rho_i g}} = \sqrt{\frac{\sigma_b}{\rho_i g}} \cdot \sqrt{h}$$

where

σ_b = bending strength of ice

ρ_i = density of ice

g = gravitational constant, 9.81 m/s^2

h = ice thickness

For average sea ice (σ_b = 500 kPa, ρ_i = 910 kg/m^3) we obtain

$$l = 7.5 \; h$$

In this study the value $8\sqrt{h}$ has been used for some margin. The minimum width of the platform is thus

$$B = 2 \cdot l = 16\sqrt{h}$$

These formulas assume that the ice beam is totally unsupported, i.e. the cavity caused by the air cushion extends below the lower surface of the ice. The formulas do not take the deflection of the ince into consideration.

The minimum length of the platform is obtained by assuming that the broken floe must have time to fall down to the bottom of the cavity before it is reached by the aft skirt. The minimum length is thus the length of the unsupported ice plus the distance the platform travels during the time the ice falls down to the bottom of the cavity.

The falling down time has been calculated as a damped free vibration. The equation is

$$m\ddot{z} + c\dot{z} + kz = 0$$

where

m = total mass, which is mass of ice and added mass of water

c = damping coefficient

k = spring constant

The solution of this equation is

$$z(t) = \frac{z_o}{\sqrt{1-\varsigma^2}} e^{-\varsigma \omega_n t} \sin(\omega_d t + \Psi)$$

where

$$z_o = h$$

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{g \varrho_w}{2h \varrho_i}}$$

$$e = 2.7183$$

$$\omega_d = \omega_n \sqrt{1-\varsigma^2}$$

$$\varsigma = \frac{c}{c_c} = \frac{1}{16}\sqrt{\frac{\varrho_i}{\varrho_w}}\sqrt[4]{h}$$

$$\Psi = \tan^{-1}\sqrt{\frac{z_o \cdot \omega_d}{z_o + \varsigma \omega_n z_o}} = \tan^{-1}\sqrt{\frac{1}{\varsigma^2} - 1}$$

$$c_c = 2\sqrt{km}, \text{ critical damping}$$

The damping coefficient c has been approximated as

$$c = \frac{\varrho_i \, g \, \frac{\pi}{4} l^2 h}{\sqrt{gl}}$$

The time t is solved from this so that

$$z(t) = 0$$

For the minimum length of the platform we get

$$L_{min} = v \cdot t + 8\sqrt{h}$$

where

v = actual speed of ship - air cushion

The estimated minimum length L_{min} is as an example printed out in the result tables of the parametric study for $v = 5$ m/s (see Appendix).

2.3 REQUIRED CUSHION PRESSURE FOR LOW SPEED BREAKING

The front part of the cavity is pushed forward by the cushion pressure. This movement is resisted by the dynamic pressure of the water. From this we get the equilibrium equation.

The static water pressure at the lower surface of the ice is (Fig. 7)

$$p_{ST} = \rho_w \cdot g \cdot (\frac{\rho_i}{\rho_w} \cdot h)$$

If we assume that the air pressure in the cavity is constant (or has an average value) p_c we will have a pressure difference which pushes the cavity forward. This pressure difference is

$$\Delta p = \rho_w \cdot g \cdot \Delta h$$

or

$$\Delta p = p_c - \rho_w \cdot g \cdot (\frac{\rho_i}{\rho_w}) \cdot h$$

If we assume that the pressure center is $\Delta h/2$ from the bottom of the ice we get as the medium pressure which pushes the cavity forward

$$\frac{1}{2}\Delta p = \rho_w \cdot g \frac{\Delta h}{2}$$

This equals the dynamic pressure in the water

$$\rho_w \cdot g \cdot \frac{\Delta h}{2} = c_D \cdot \frac{1}{2} \cdot \rho_w v^2$$

After manipulations we get

$$v_{max} = \sqrt{\frac{p_c - \rho_i \, g \, h}{c_D \, \rho_w}}$$

or

$$p_c = c_D \, \rho_w \, v_{max}^2 + \rho_i \, g \, h$$

where

c_D = drag coefficient, which is 0.07 in this case.
This is the value for a streamlined body with almost no friction.

ρ_w = density of water

ρ_i = density of ice

This is a first approximation of the maximum speed which can be obtained when breaking level ice with an air cushion platform. At this stage the deflection of the ice is not taken into consideration in the calculations. A certain deflection corresponds to a certain ice thickness, which in turn corresponds to a certain cushion pressure.

From observations made during tests it is known that the deflection of the ice is noticeable especially at the sides of the platform when the cushion pressure interacts with the wave pattern created by the platform. Sometimes the deflection may be so big that the breaking is not possible, especially during the melting period after noon when the sun has made the ice more elastic.

2.4 POWER REQUIREMENT FOR THE AIR CUSHION PLATFORM

The airflow needed to create the required cushion pressure is calculated from the following formula

$$Q = 0.63 \; H_e \cdot l_c \sqrt{\frac{2 \cdot p_c}{\rho_A}}, \; (m^3/s)$$

where

H_e = average gap between skirt and ice or water (m)

l_c = air cushion perimeter, which is the length of the lower edge of the skirt (m)

p_c = cushion pressure (Pa)

ρ_A = density of air, here taken as 1.4 kg/m^3. This is the average density at normal air pressure for temperatures 0...-20 °C.

The physical background for this formula is that the pressure drop of the air when leaking out under the skirt must be the same as the cushion pressure. The value for H_e has been determined through tests carried out by Wärtsilä. (H_e = 0.02 m in this study.)

The dynamical pressure in the ducts after the fans is

$$p_{DYN} = c_D \cdot \frac{1}{2} \cdot \rho_A \cdot v_A^2$$

where

c_D = loss coefficient, here taken as 1.2; the value is supported by tests made by Wärtsilä

v_A = speed of air in ducts. The cross area of the ducts is usually chosen so that the air speed is in the range 20...30 m/s; 25 m/s is assumed here

For the total pressure we then get

$$p_{TOT} = p_c + p_{DYN}$$

The power for the air cushion is calculated from

$$P_{AC} = \frac{p_{TOT} \cdot Q}{\eta}$$

where

η = total efficiency of the fan(s); 0.8 is assumed

2.5 VERTICAL FORCES TRANSMITTED FROM AIR CUSHION TO SHIP WHEN BREAKING ICE

The vertical minimum force needed to create the cavity in front of the ship is

$$F = B_{AC} \; L_{min} \; p_c$$

These have been printed out in the result tables in the Appendix for the speed v = 5 m/s.

The weight of the structure of a platform of conventional design has been estimated to get the order of magnitude of the forces which have to be transformed between the ship and the structure and/or to get the weight of the possible platform ballast. These forces are exemplified in the Table 1. The upwards acting force of the bow is of the same order of magnitude as the weight of the platform for smaller ships and thimmer ice but approximately 2.5 times the weight of the platform for bigger ships.

B (m)	h (m)	F (kN)	G (kN)	F - G (kN)
12	0.4	467	220	247
12	0.7	930	350	580
12	1	1490	490	1000
16	0.4	622	240	382
16	0.7	1241	467	774
16	1	1986	654	1332
20	0.4	778	366	412
20	0.7	1551	583	968
20	1	2482	817	1666
20	1.5	4292	1238	3054
20	2	6445	1710	4735
30	1	3724	1225	2499
30	1.5	6438	1857	4581
30	2	9668	2565	7103
40	1	4965	1634	3331
40	1.5	8584	2642	5942
40	2	12891	3420	9471

where

F = vertical force (kN)

G = estimated platform weight (kN)

Table 1. Weight of platform and vertical force transmitted between ship and platform.

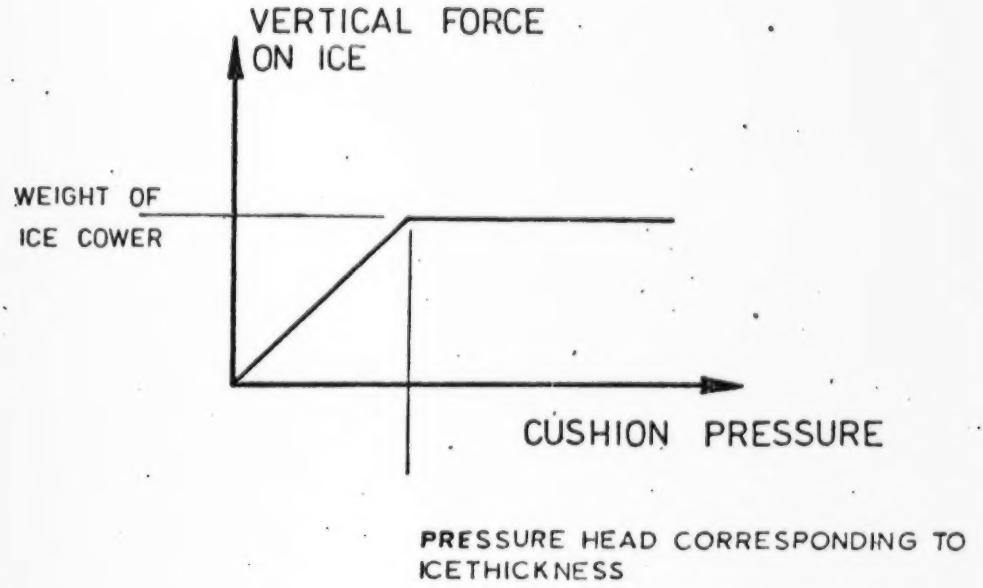


Figure 6 Relation between cushion pressure and vertical force on ice.

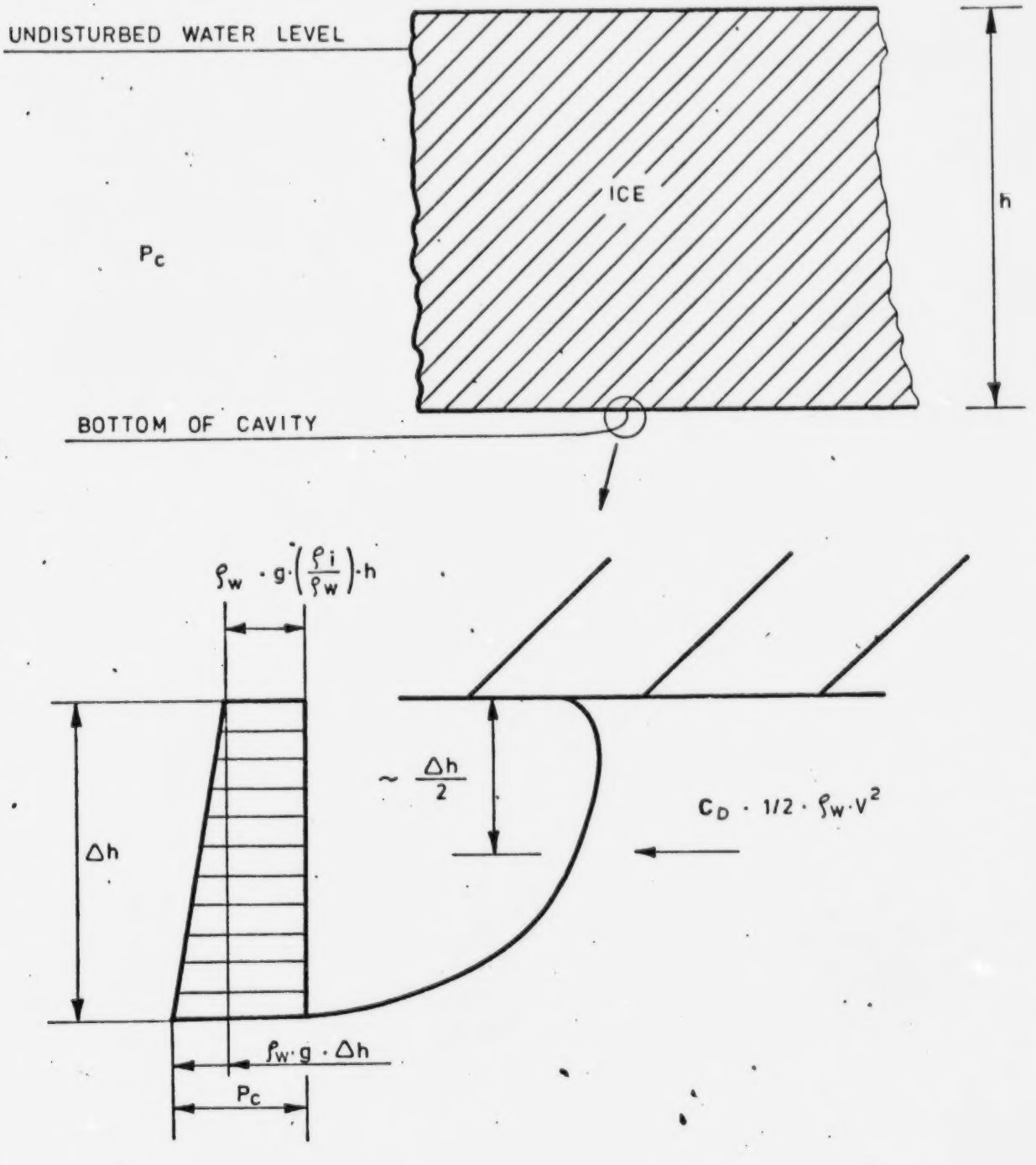


Figure 7 Pressure equilibrium (see text).

3 PARAMETRIC STUDY

The influence of the following parameters on the needed power has been studied:

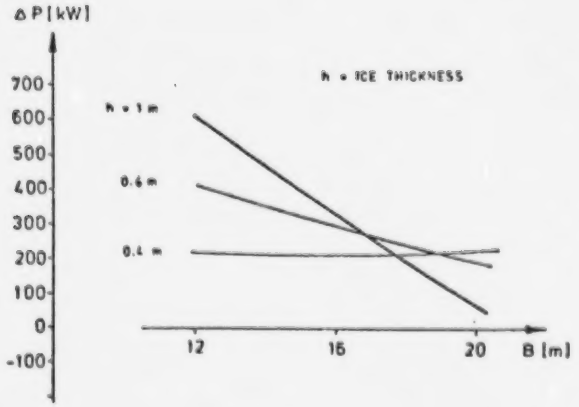
- ice thickness .
- speed
- ship breadth
- shape of fore ship. Two basic hull forms have been analysed, one good icebreaking ship (hull form 1) and a ship not designed for icebreaking (hull form 2).

The main dimensions ratios of the ship have been kept constant, L/B = 6 and B/T = 3.

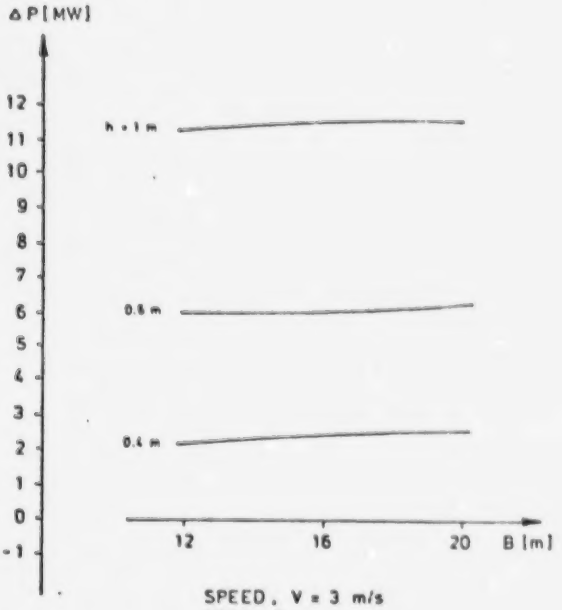
The results of the parametric study are listed in the Appendix.

The breadth of the air cushion platform is the same as the breadth of the ship ($B_{WL} = B_{AC}$). For a ship breadth (B) of 12 m and an ice thickness of 1 m, it is questionable whether the 12 m breadth of the air cushion is enough to break the ice ($16\sqrt{h} > 12$, h = 1 m). However, also this result has been reported for comparison.

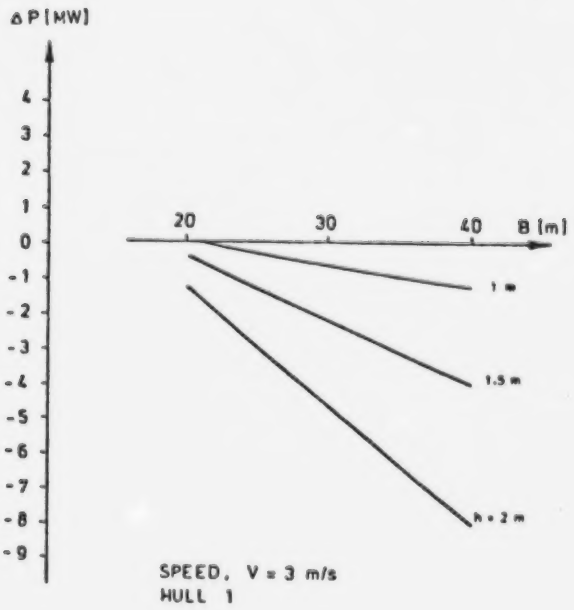
A compilation of the results is presented in Figs. 8 and 9.



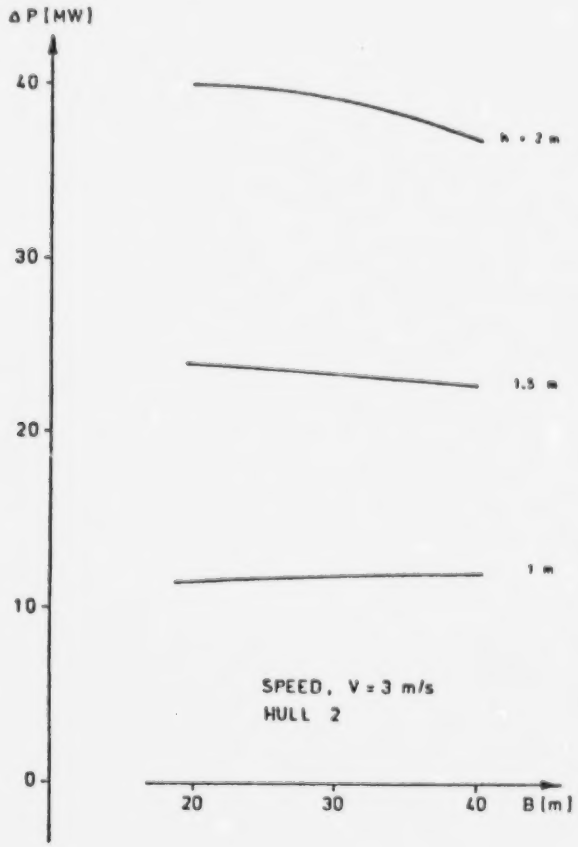
SPEED , V = 3 m/s
HULL 1



SPEED , V = 3 m/s
HULL 2

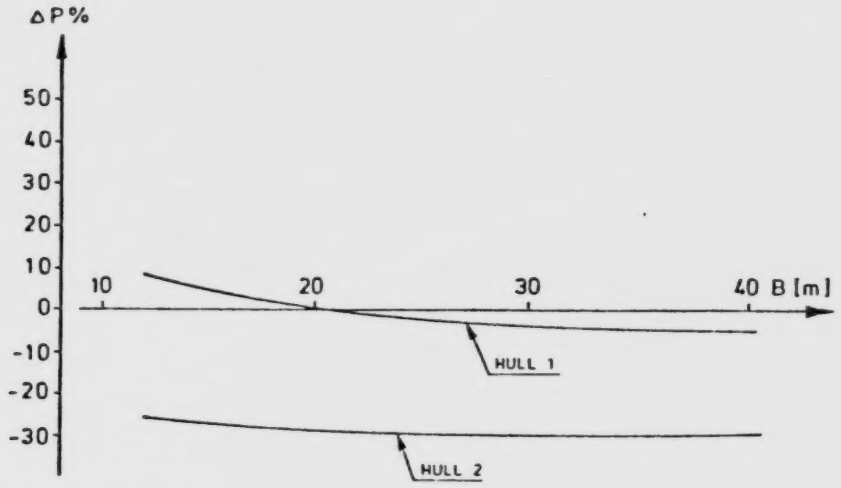


SPEED, V = 3 m/s
HULL 1



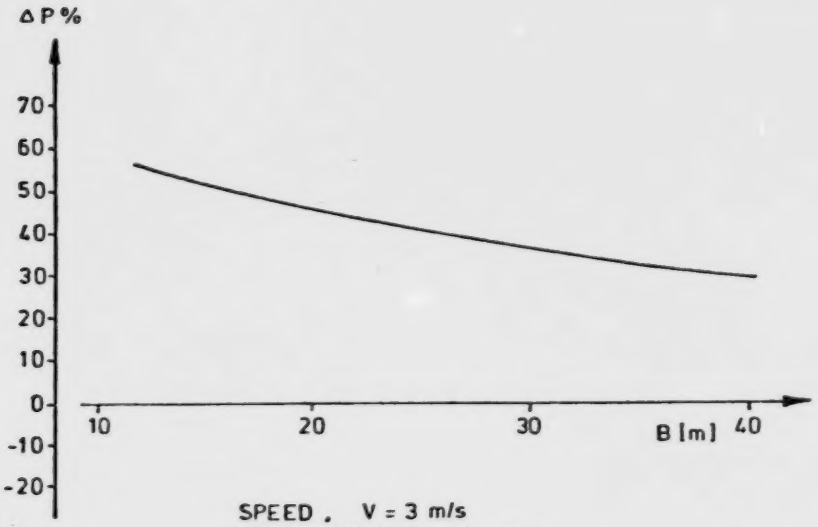
SPEED, V = 3 m/s
HULL 2

Figure 8 Gain in total power due to use of air cushion platform.



SPEED , V = 3 m/s
ICE THICKNESS , h = 1 m.

HULL 1 WITHOUT AIR CUSHION
PLATFORM USED AS REFERENCE



SPEED , V = 3 m/s
ICE THICKNESS , h = 1 m

HULL 2 WITHOUT
AIR CUSHION PLATFORM
USED AS REFERENCE

Figure 9 Gain in total power due to use of air cushion platform.

4 INFLUENCE OF PLATFORM WEIGHT AND VERTICAL FORCE ON THE TRIM AND STABILITY OF THE SHIP

The changes of trim and stability have been checked for two reference ships.

The vessels are:

1. Ship 1

-	Length	174 m
-	Breadth	24,5 m
-	Arctic draught	9 m

2. Ship 2

-	Length	75,9 m
-	Breadth	12,6 m
-	Draught	3,0 m

The results are presented in Table 2.

The change of trim is the most critical parameter. It puts weight limitation on the structure of the platform and limits the maximum ice thickness which can be broken by the air cushion method. The change of stability (metacentric height) and the draught are reasonable for these two example ships. Both are ship types that usually do not have stability problems.

Vessel	Ice thickness (m)	Change of draught (cm)	Change of trim (cm)	Change of metacentric height (m)
Ship 1				
air cushion icebreaking	0.4...1	+1...+6	+10...+45	0
normal mode of operation	0.4...1	-1...-3	-10...-22	-0.07...-0.1
air cushion icebreaking	1...2	+6...+20	+45...+130	0
normal mode of operation	1...2	-3...-7	-22...-47	-0.1...-0.15
Ship 2				
air cushion icebreaking	0.4...1	+3...+12	+12...+40	0
normal mode of operation	0.4...1	-3...-6	-20..-.80	-0.1...-0.12

Table 2. Change of ship draught, trim and metacentric height due to air cushion platform and mode of operation.

The change of metacentric height in the cushion icebreaking mode is small because the force acts close to the center of gravity of the ship. The change of metacentric height in normal mode of operation in Table 2 is for the case when the platform is lifted up on the forecastle deck.

5 DIFFERENT CONCEPTS OF INTEGRATED AIR CUSHION PLATFORM

This phase included a literature study and a number of "brain stormings". This work gave numerous different solutions. The technical aspects and the feasibility of these concepts were briefly investigated and left nine solutions for further investigation. Four of these were chosen for the further analysis.

5.1 EXPANDED FLARE BOW (FIG. 10)

The deck is expanded at the bow approximately in the same manner as on an aircraft carrier. The skirt is attached to the expanded deck.

Advantages:

- rigid structure
- possible to add on existing ships

Disadvantages:

- risk for slamming loads in big waves
- harbour operations might be hampered

5.2 HEAVY-LIFT EQUIPMENT FOR LIFTING THE PLATFORM (FIG. 11)

The platform is lifted up on the forecastle deck when the platform is not in use.

Advantages:

- relatively fast change of mode of operation according to changes in ice conditions
- good seagoing capability
- easy maintenance of skirt when lifted on deck

Disadvantages:

- loss of deadweigt and weakened stability due to the heavy structure
- vibration problems might occur in the lifting cantilever beams
- the visibility from the bridge is reduced
- not easily installed on existing ships
- platform must be ballasted
- the lifting mechanism needs maintenance

5.3 THREE RETRACTABLE SKIRT-SUPPORTING BEAMS (FIG. 12)

The three retractable beams form a frame in front of the ship. The skirt segments are attached to these beams. The upper surface of the space between the beams is covered with a flexible, airtight material.

The beams can be locked in position when operating in the air cushion breaking mode and turned up on deck when not in use.

Advantages:

- good seagoing capability
- can be built on existing ships
- the maintenance and replacement of skirt segments can be done while the ship is making headway
- light structure

Disadvantages:

- structural problems of the beams
- the in-position-locking system and turning mechanism need maintenance.

5.4 HORIZONTALLY RETRACTABLE AIR CUSHION PLATFORM (FIG. 13)

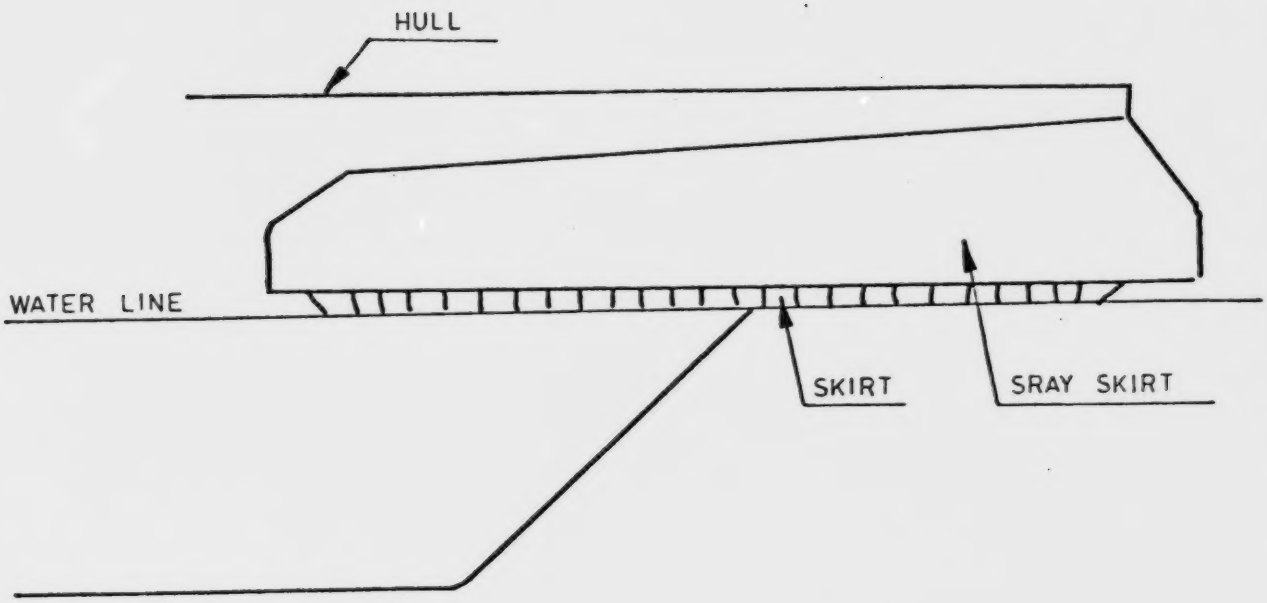
The platform can be drawn back horizontally over the bow when not in use.

Advantages:

- good seagoing capability
- does not hamper harbour operations

Disadvantages:

- the design affects the steel structure of the forecastle deck
- icing may occur on the retracting mechanism of the skirt



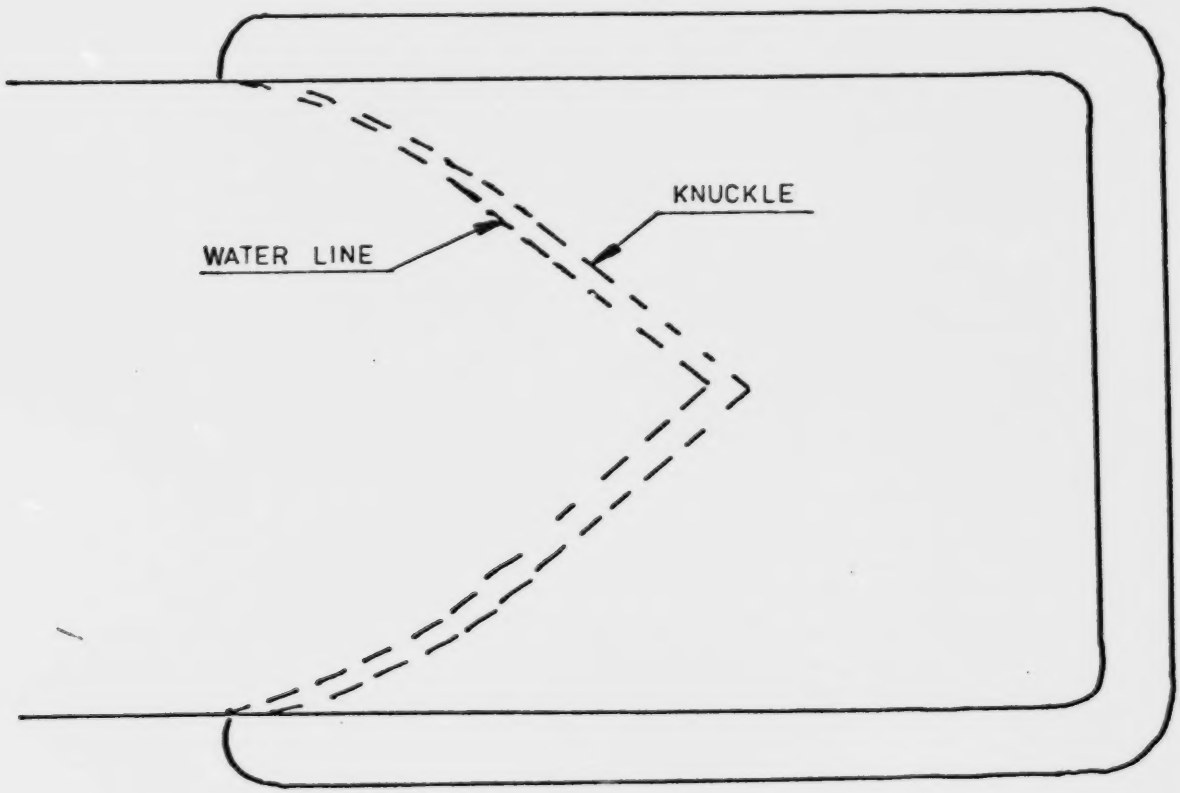


Figure 10 Expanded flare bow.

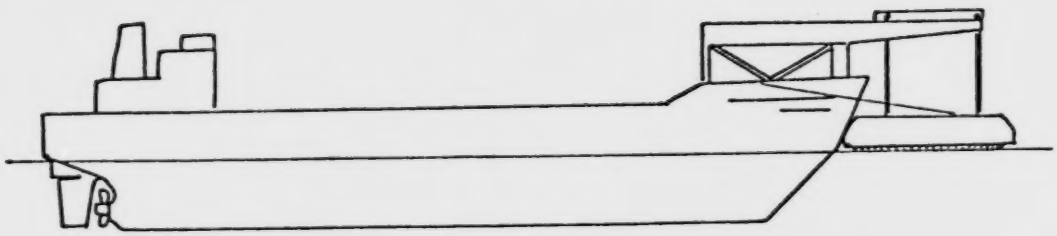


Figure 11 Heavy-lift equipment for lifting the platform.

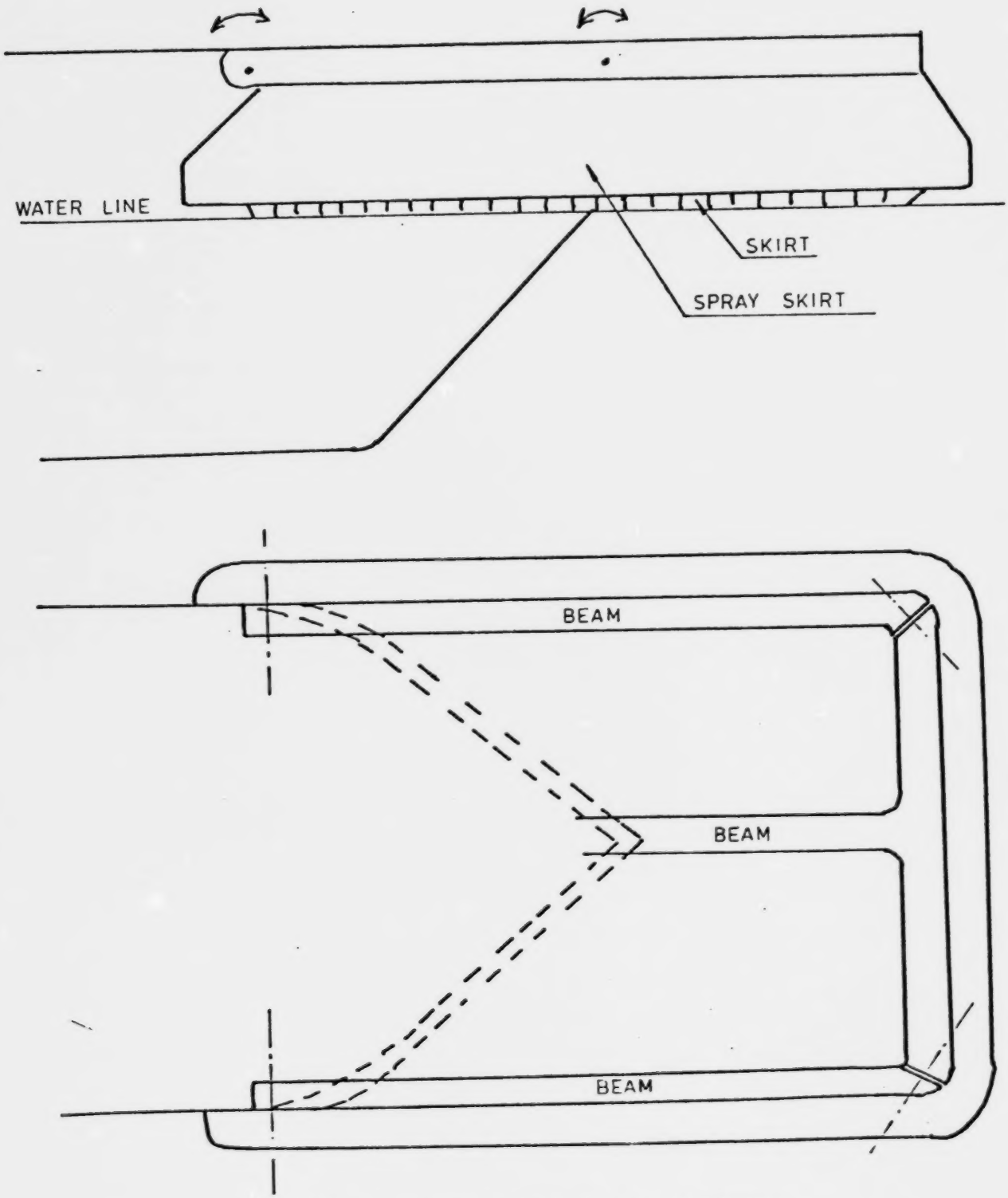


Figure 12 Three retractable skirt-supporting beams.

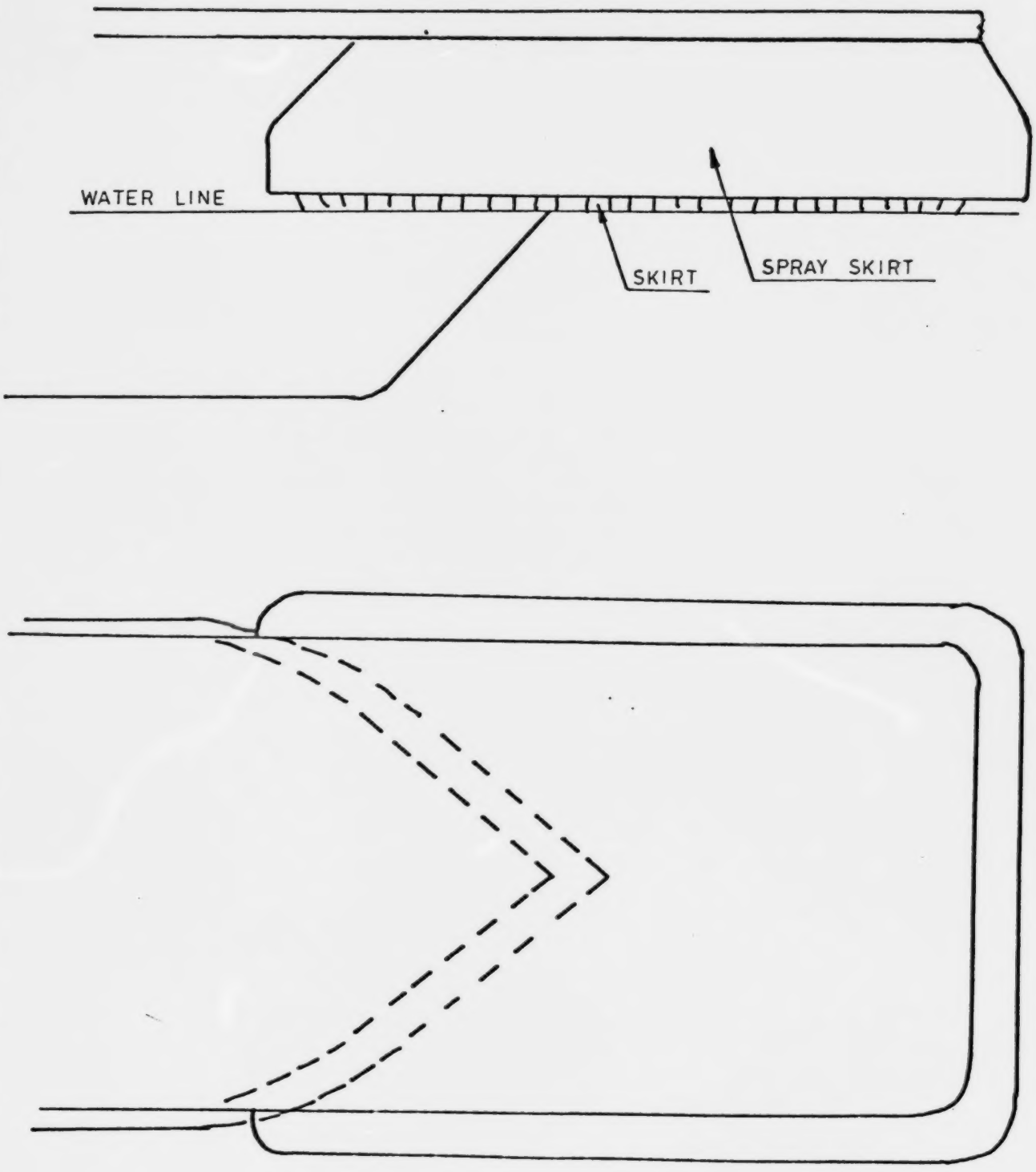


Figure 13 Horizontally retractable air cushion platform.

6 PROPOSAL OUTLINE AND COST ESTIMATE FOR FEASIBILITY STUDY

The following continuation of the study is proposed for evaluating the feasibility of the chosen consept:

a) Full scale tests

The objective of these tests is to calibrate and to develop further the methods presented in this report for predicting the icebreaking capability of the air cushion platform, and for determining the necessary characteristics of it. In addition, the following items not covered by this report have to be included:

- The influence of the bending of the ice before failure.
- The ice trajectories.
- The influence of wave making on the failure of the ice field and the speed of advance.
- The influence of vibration on the failure of the ice field.
- Influence of cushion air flow.

Full scale testing is considered superior to model testing for these tests. Satisfactory results, obtained from model tests, for this specific test series, would require correct scaling of a number of ice characteristics, which cannot be made with the modelling technique currently available at any laboratory for icebreaking tests.

After completion of this phase methods will be available for determining optimum dimensions and characteristics of an air cushion platform for different ice thicknesses.

The study will require about three weeks of testing. The whole study will take about five months and the costs are estimated to be $ 450,000 (Canadian). This price is based on the use of an air cushion platform available at the Wärtsilä Helsinki Shipyard.

b) System analysis and conceptual design

During the initial phase the final concept will be chosen. A conceptual design of this concept will be made and this design will be analyzed for:

- hydrostatic stability
- seakeeping, by model tests (3 wave spectrums)

The duration of this study is four months and the costs are estimated to be $ 125,000 (Canadian).

c) Final capability prediction and feasibility study

The duration of this study is four months and the costs are estimated to be $ 75,000 (Canadian).

7 CONCLUSIONS

In this study the feasibility of two basic ship types was investigated:

- A medium-sized ship operating in subarctic areas.
- A large ship operating in arctic areas.

In both cases an icebreaking ship and a ship not designed for icebreaking were studied.

The results show that

- when the bow of the ship is not designed for breaking ice, the use of an air cushion platform in front of the ship gives a net benefit of about 20 to 45 % in power consumption, when operating in level ice at a speed of 3 m/s.

- when the bow of the ship is designed for icebreaking, the net benefit in power consumption ranges from 0 % to 10 % in subarctic ice (up to 1.0 m thickness) at a speed of 3 m/s.

- in ice thicker than 1.0 m the use of an air cushion platform increases the total power consumption for a ship with good icebreaking capability.

Generally the study shows the following relationships:

- The better the design of the bow for icebreaking, the smaller the savings.
- The wider the ship, the smaller the savings for good icebreaking hull.
- The lower the speed, the higher the savings.

In this study four possible concepts for combining the air cushion platform to a ship were proposed. The final choice of concept requires further investigation of the technical realization, and is not included in this study.

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10. Report No. B 51. T/A Suunnan jääkokeet Suomenlahdella 1981-03-17...19. (Ice test with the M/S Suunta on the Gulf of Finland 1981-03-17...19.) Torsten Heideman, Gustav Lindqvist, Berndt Lönnberg. Wärtsilä Helsinki Shipyard. Unpublished.

APPENDIX

Results of Parametric Study.

The symbols used in the computer output are:

LWL	=	length of ship's waterline (m)
BWL	=	breadth of ship (m)
BAC	=	breadth of air cushion platform (m)
H	=	ice thickness (m)
V	=	speed of ship (m/s)
R(S)	=	level ice resistance of ship without air cushion platform (kN)
R(S+A)	=	level ice resistance of ship - air cushion combination (kN)
P(S)	=	power on shaft of ship without air cushion platform (kN)
P(S+A)	=	power on shaft of ship when using air cushion platform (kN)
P(A)	=	power of air cushion platform (kW)
P ((S+A)+A)	=	power on shaft of ship + power of air cushion i.e. P ((S+A)+A) = P (S+A) + P (A) (kW)
DIF	=	P ((S+A) + A) - P (S) (kW), i.e. gain in total power, due to use of air cushion in front of the ship.

Table A. Symbols for computer output.

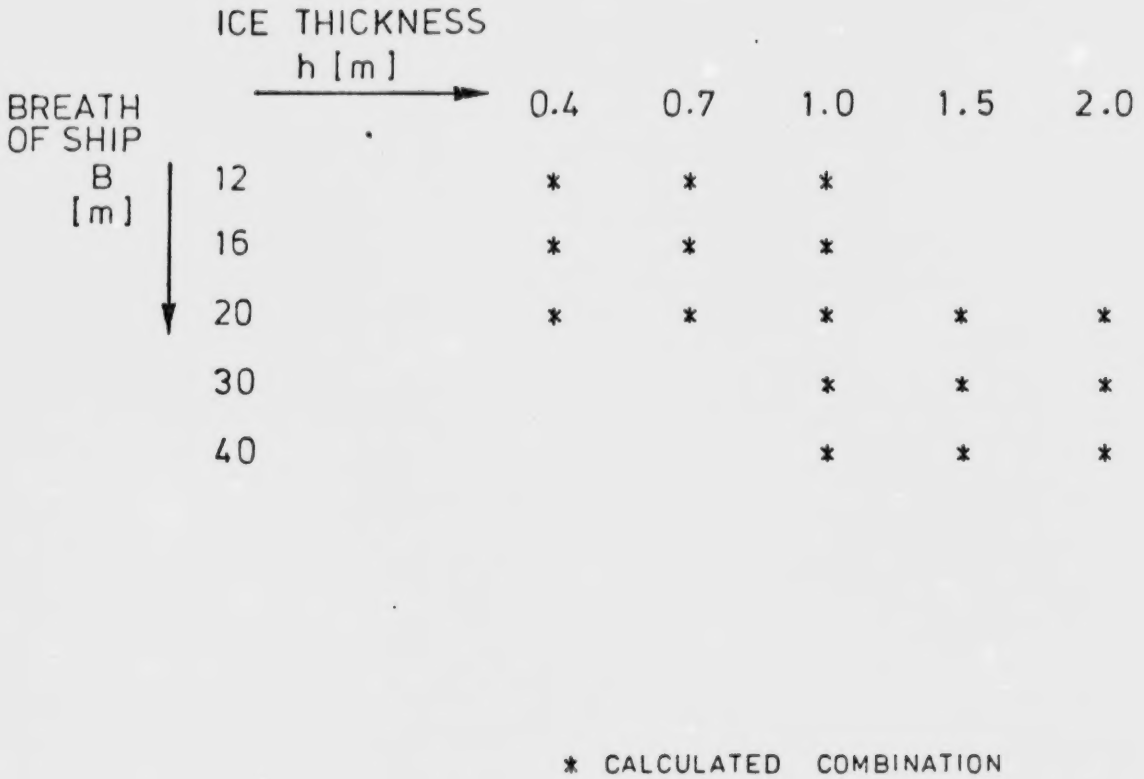


Figure A Principle of variation of parameters. Each combination has been calculated both for an icebreaking hull form and for a conventional hull form.

Table No.	Fig. No.	hull form	L (m)	B (m)	T (m)	h (m)
1	1	1	72	12	4	0.4
1	2	1	72	12	4	0.7
1	3	1	72	12	4	1
2	4	2	72	12	4	0.4
2	5	2	72	12	4	0.7
2	6	2	72	12	4	1
3	7	1	96	16	5.3	0.4
3	8	1	96	16	5.3	0.7
3	9	1	96	16	5.3	1
4	10	2	96	16	5.3	0.4
4	11	2	96	16	5.3	0.7
4	12	2	96	16	5.3	1
5	13	1	120	20	6.66	0.4
5	14	1	120	20	6.66	0.7
5, 7	15	1	120	20	6.66	1
6	16	2	120	20	6.66	0.4
6	17	2	120	20	6.66	0.7
6, 8	18	2	120	20	6.66	1
7	19	1	120	20	6.66	1.5
7	20	1	120	20	6.66	2
8	21	2	120	20	6.66	1.5
8	22	2	120	20	6.66	2
9	23	1	180	30	10	1
9	24	1	180	30	10	1.5
9	25	1	180	30	10	2
10	26	2	180	30	10	1
10	27	2	180	30	10	1.5
10	28	2	180	30	10	2
11	29	1	240	40	13.3	1
11	30	1	240	40	13.3	1.5
11	31	1	240	40	13.3	2
12	32	2	240	40	13.3	1
12	33	2	240	40	13.3	1.5
12	34	2	240	40	13.3	2

Table B. Variation of parameters. (See Figure A.)

SHIP CHARACTERISTICS

LWL = 72.5 M
BWL = 13.0 M
BAC = 12.0 M
HULL 1

TABLE 1

H= 0.4 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	126	94	1141	706	127	928	219
1.00	150	111	1383	1015	145	1160	229
2.00	170	136	1587	1390	162	1509	337
3.00	208	166	2327	1924	189	2113	314
4.00	241	198	3044	2622	229	2851	193
5.00	276	234	3772	3527	283	3810	142

VERTICAL FORCE = 466.72 KN
EST.PLATFORM LENGTH = 7.31 M

H= 0.7 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	291	201	2447	1688	348	2036	411
1.00	337	237	2884	2116	365	2481	404
2.00	397	279	3613	2790	395	3185	428
3.00	440	300	4528	3677	441	4117	411
4.00	502	418	5608	4816	503	5320	368
5.00	581	491	7065	6184	586	6770	293

VERTICAL FORCE = 510.44 KN
EST.PLATFORM LENGTH = 9.69 M

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	492	341	4140	2861	635	3496	643
1.00	545	398	4819	3516	666	4182	636
2.00	632	481	5845	4531	714	5245	600
3.00	729	578	7060	5009	701	6569	611
4.00	837	680	8706	7346	869	8219	567
5.00	953	802	10675	9238	983	10221	453

VERTICAL FORCE = 1439.46 KN
EST.PLATFORM LENGTH = 11.69 M

SHIP CHARACTERISTICS

LWL = 72.0 M
BWL = 12.0 M
BMC = 12.0 M

HULL2

TABLE 2

H= 0.4 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	314	112	3148	988	137	1075	2073
1.00	407	145	3798	1303	145	1448	2145
2.00	455	192	4877	1915	162	2077	2800
3.00	511	248	5189	2528	189	2917	2272
4.00	573	310	6230	3741	229	3969	2260
5.00	640	377	7646	5019	283	5301	2346

VERTICAL FORCE = 466.72 KN
EST.PLATFORM LENGTH = 7.31 M

H= 0.7 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	940	236	7857	1979	340	2327	5530
1.00	1008	304	9768	2684	365	3049	5716
2.00	1107	403	10002	3812	395	4207	5794
3.00	1223	519	11653	5033	441	5573	5980
4.00	1351	647	13544	6989	503	7492	6052
5.00	1489	785	15746	9114	586	9700	6046

VERTICAL FORCE = 930.44 KN
EST.PLATFORM LENGTH = 9.69 M

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	1750	395	14719	3313	635	3948	10771
1.00	1356	503	16013	4420	666	5086	10927
2.00	2015	660	17949	6101	714	6814	11134
3.00	2199	844	20334	8255	781	9036	11298
4.00	2403	1048	23020	10763	869	11633	11387
5.00	2623	1268	26438	13701	983	14684	11754

VERTICAL FORCE = 1489.46 KN
EST.PLATFORM LENGTH = 11.63 M

SHIP CHARACTERISTICS
LWL = 90.0 M
BWL = 16.8 M
DRAFT = 10.4 M

HULL 1

TABLE 3

H= 0.4 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	196	144	1797	1310	469	1379	217
1.00	207	161	1872	1478	173	1696	216
2.00	232	187	2160	1904	190	2130	226
3.00	262	216	3022	2588	230	2818	204
4.00	295	249	3938	3447	277	3724	213
5.00	330	284	5045	4608	342	4950	146

VERTICAL FORCE = 623.39 KN
EST.PLATFORM LENGTH = 7.31 M

H= 0.7 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	393	305	1304	2562	422	2984	320
1.00	429	341	1817	3045	441	3486	331
2.00	481	393	2721	3829	475	4303	318
3.00	542	455	4089	4870	527	5397	292
4.00	610	522	5883	6225	599	6824	259
5.00	683	595	7785	7867	694	8560	224

VERTICAL FORCE = 1244.53 KN
EST.PLATFORM LENGTH = 5.65 M

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	648	512	5418	4298	762	5060	358
1.00	705	569	6197	5029	794	5824	364
2.00	788	652	7535	6173	847	7019	329
3.00	885	749	9279	7628	921	8550	328
4.00	993	857	11285	9451	1021	10472	313
5.00	1109	973	13528	11644	1150	12793	235

VERTICAL FORCE = 1985.94 KN
EST.PLATFORM LENGTH = 11.63 M

SHIP CHARACTERISTICS

LWL = 96.0 M
BWL = 16.0 M
DRC = 10.0 M
ALFA=
HULL2

TABLE 4

H= 0.4 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+H)+A) KW	DIF KW
0.00	455	173	3824	1452	164	1622	2202
1.00	487	205	4393	1872	178	2050	2343
2.00	535	254	5102	2560	198	2756	2344
3.00	541	310	5174	3490	230	3720	2446
4.00	653	372	7502	4713	277	4990	2513
5.00	720	439	9113	6245	342	6587	2508

VERTICAL FORCE = 620.20 KN
EST.PLATFORM LENGTH = 7.31 M

H= 0.7 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+H)+A) KW	DIF KW
0.00	1004	361	8164	3026	422	9448	5715
1.00	1117	420	10065	3825	441	4265	5800
2.00	1256	527	11549	5009	475	5514	5035
3.00	1372	640	13365	6663	527	7190	6175
4.00	1500	772	15552	8646	599	9245	6307
5.00	1639	910	18132	11049	694	11743	6395

VERTICAL FORCE = 1240.58 KN
EST.PLATFORM LENGTH = 9.69 M

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+H)+A) KW	DIF KW
0.00	1976	596	16625	5019	762	5780	10845
1.00	2084	700	17960	6206	794	7000	10960
2.00	2242	863	20142	8053	847	8901	11241
3.00	2427	1047	22805	10034	921	11256	11550
4.00	2630	1251	25756	13240	1021	14261	11696
5.00	2850	1471	29538	16487	1150	17636	11902

VERTICAL FORCE = 1905.94 KN
EST.PLATFORM LENGTH = 11.68 M

TABLE 5

UNIT CHARACTERISTICS

LWL = 126.0 M
BWL = 29.0 M
DPC = 20.0 M

HULL 1

H= 0.4 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	251	202	2119	1697	201	1899	210
1.00	269	220	2443	2009	211	2220	223
2.00	294	245	3009	2547	234	2780	229
3.00	324	274	4125	3332	271	3603	522
4.00	356	307	4926	4401	326	4726	200
5.00	392	342	6073	5835	401	6239	133

VERTICAL FORCE = 777.87 KN
EST.PLATFORM LENGTH = 7.31 M

H= 0.7 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	509	424	4255	3556	496	4052	203
1.00	545	459	4952	4103	515	4618	333
2.00	597	512	6769	5004	554	5558	211
3.00	658	578	7046	6241	613	6854	192
4.00	726	641	8640	7782	694	8474	166
5.00	799	714	10675	9782	802	10583	91

VERTICAL FORCE = 1550.72 KN
EST.PLATFORM LENGTH = 9.69 M

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	826	705	6907	5920	859	6809	98
1.00	883	762	7797	6739	923	7661	136
2.00	966	846	9095	8002	980	8982	100
3.00	1064	942	10302	9680	1062	10742	60
4.00	1171	1050	12968	11770	1173	12943	20
5.00	1287	1167	15590	14425	1316	15742	-152

VERTICAL FORCE = 3482.43 KN
EST.PLATFORM LENGTH = 11.63 M

SHIP CHARACTERISTICS
LWL = 120.0 M
BWL = 20.0 M
BAC = 20.0 M
HULL2

TABLE 6

H= 0.4 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	544	244	4578	2046	201	2247	2531
1.00	577	276	5139	2510	211	2739	3414
2.00	625	324	6430	3303	234	3536	2907
3.00	681	380	7952	4381	271	4652	2000
4.00	743	442	9782	5786	326	6111	2671
5.00	810	509	10754	7660	401	8061	2693

VERTICAL FORCE = 777.87 KN
EST.PLATFORM LENGTH = 7.31 M

H= 0.7 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	1257	565	10071	4222	496	4718	5853
1.00	1320	571	11024	5027	516	5543	5481
2.00	1424	676	13151	6460	554	7015	6147
3.00	1540	756	15195	8244	613	8857	6338
4.00	1668	914	17530	10446	694	11141	6393
5.00	1805	1052	20691	13249	802	14051	6550

VERTICAL FORCE = 1550.70 KN
EST.PLATFORM LENGTH = 9.69 M

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	D.F KW
0.00	2231	829	18763	6954	989	7943	10920
1.00	2338	936	20240	8276	923	9200	11140
2.00	2496	1094	23556	10207	980	11187	11369
3.00	2680	1278	28548	13839	1062	13901	11646
4.00	2884	1482	33067	15879	1173	17052	12015
5.00	3104	1702	32062	19603	1316	20920	12143

VERTICAL FORCE = 2482.43 KN
EST.PLATFORM LENGTH = 11.60 M

SHIP CHARACTERISTICS
LWL = 130.0 M
BWL = 20.0 M
BAC = 20.0 M
HULL 1

TABLE 7

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	826	705	6807	5820	899	6809	98
1.00	883	762	7297	6708	924	7661	136
2.00	966	846	8085	8002	980	8982	103
3.00	1064	943	10201	9000	1062	10712	60
4.00	1171	1050	11764	11770	1173	12943	20
5.00	1287	1167	15590	14425	1316	15742	-152

VERTICAL FORCE = 2482.43 KN
EST.PLATFORM LENGTH = 11.63 M

H= 1.5 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	1475	1298	12419	10850	1737	12629	-210
1.00	1572	1394	12681	12135	1804	13939	-258
2.00	1714	1535	15755	14185	1899	16084	-329
3.00	1879	1700	19296	16618	2028	18645	-349
4.00	2061	1882	21361	19745	2193	21938	-578
5.00	2258	2079	24987	23293	2400	25694	-707

VERTICAL FORCE = 4291.76 KN
EST.PLATFORM LENGTH = 14.17 M

H= 2 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	2269	2034	18965	17067	2813	19880	-915
1.00	2409	2174	20952	18923	2922	21845	-893
2.00	2614	2379	23619	21662	3068	24730	-1111
3.00	2853	2618	26972	25012	3255	28267	-1295
4.00	3118	2883	31020	29089	3487	32576	-1556
5.00	3404	3169	35992	33812	3770	37582	-1590

VERTICAL FORCE = 6445.35 KN
EST.PLATFORM LENGTH = 16.44 M

SHIP CHARACTERISTICS

LWL = 120.0 M
BWL = 30.0 M
BAC = 20.0 M
HULL2

TABLE 8

H= 1 M

V M/S	R(S) KN	R(S+S) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	2231	829	10763	6954	989	7943	10020
1.00	2336	906	20240	8276	923	9200	11040
2.00	2496	1094	21050	10207	900	11107	11043
3.00	2580	1278	28546	12939	1062	13901	11645
4.00	2884	1492	29067	15879	1173	17052	12052
5.00	3104	1702	33062	19603	1316	20920	12142

VERTICAL FORCE = 2482.43 KN
EST.PLATFORM LENGTH = 11.63 M

H= 1.5 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	4421	1504	37185	12524	1738	14262	22923
1.00	4603	1687	39380	14684	1804	16487	22893
2.00	4873	1954	43477	17880	1899	19779	23698
3.00	5182	2256	47911	21849	2020	23876	24034
4.00	5520	2611	53119	26579	2193	28772	24348
5.00	5900	2984	59158	31969	2400	34369	24789

VERTICAL FORCE = 4391.76 KN
EST.PLATFORM LENGTH = 14.17 M

H= 2 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	7308	2334	61288	19590	2813	22403	38885
1.00	7573	2600	64284	22398	2922	25320	38964
2.00	7961	2988	69668	26943	3068	30011	39657
3.00	8415	3441	76040	32415	3255	35670	40369
4.00	8917	3943	83131	38553	3487	42040	41091
5.00	9458	4485	91382	46050	3770	49820	41562

VERTICAL FORCE = 6445.35 KN
EST.PLATFORM LENGTH = 16.44 M

SHIP CHARACTERISTICS
LWL = 180.0 M
BWL = 30.0 M
BAC = 30.0 M
HULL 1

TABLE 9

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	1350	1675	11950	14699	1307	11905	-555
1.00	1415	1892	12524	11771	1244	13015	-520
2.00	1490	1415	13217	13517	1313	14830	-550
3.00	1595	1512	14130	15729	1414	17143	-610
4.00	1702	1620	15132	13656	1553	20209	-707
5.00	1819	1736	16162	22396	1732	24128	-966

VERTICAL FORCE = 3713.64 KN
EST.PLATFORM LENGTH = 11.63 M

H= 1.5 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	2257	2310	19704	19904	2022	21707	-2006
1.00	2453	2406	21529	20946	2392	23338	-1803
2.00	2594	2547	22752	23536	2501	26037	-2057
3.00	2759	2712	24230	26756	2653	29409	-2179
4.00	2941	2894	25828	30880	2852	33733	-2405
5.00	3138	3091	27201	35077	3103	38980	-2779

VERTICAL FORCE = 6437.63 KN
EST.PLATFORM LENGTH = 14.17 M

H= 2 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	3529	3579	29500	30040	3711	33750	-4170
1.00	3679	3719	31997	32378	3825	36203	-4306
2.00	3864	3934	33537	35739	3988	39725	-4329
3.00	4123	4164	35820	40150	4202	44351	-4731
4.00	4388	4429	44913	45078	4472	49550	-4641
5.00	4674	4715	51001	51356	4804	56100	-5160

VERTICAL FORCE = 9661.04 KN
EST.PLATFORM LENGTH = 19.19 M

SHIP CHARACTERISTICS
LWL = 180.0 M
BWL = 30.0 M
BAC = 30.0 M
HULL2

TABLE 10

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	2973	1512	24854	12592	1207	13899	10255
1.00	3081	1620	26798	14320	1244	15565	11703
2.00	3229	1778	29771	16745	1313	18058	11713
3.00	3433	1962	33386	19969	1414	21384	11953
4.00	3627	2166	37589	23882	1553	25435	13154
5.00	3847	2386	43074	28757	1732	30489	12585

VERTICAL FORCE = 3723.64 KN
EST.PLATFORM LENGTH = 11.60 M

H= 1.5 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	5638	3708	47129	32739	2322	25051	22079
1.00	5821	3891	50172	25165	2392	27556	22615
2.00	6053	4123	54693	28899	2501	31400	23293
3.00	6300	4370	60162	33768	2653	36421	23741
4.00	6545	4615	66571	39515	2851	42367	24205
5.00	7118	4188	73770	46552	3103	49654	24116

VERTICAL FORCE = 6437.65 KN
EST.PLATFORM LENGTH = 14.17 M

H= 2 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	8750	4139	76124	34806	2711	38616	37507
1.00	9015	4404	80097	38516	3625	42341	37955
2.00	9404	4812	86664	43393	3988	47386	38278
3.00	10157	5366	96371	49839	4102	54041	39330
4.00	10659	5768	101596	57424	4472	61896	39699
5.00	11201	6310	111423	66759	4004	71563	39861

VERTICAL FORCE = 9658.03 KN
EST.PLATFORM LENGTH = 12.44 M

SHIP CHARACTERISTICS
LWL = 240.0 M
BWL = 40.0 M
BAC = 40.0 M
HULL 1

TABLE 11

H= 1 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	1999	1953	16511	16395	1524	17919	-1168
1.00	2057	2010	18146	17770	1566	19336	-1130
2.00	2139	2094	20154	20001	1645	21646	-1262
3.00	2236	2191	22456	22984	1766	24750	-1265
4.00	2344	2290	27201	26781	1933	28714	-1494
5.00	2460	2415	32153	31799	2149	33948	-1732

VERTICAL FORCE = 4964.85 KN
EST.PLATFORM LENGTH = 11.63 M

H= 1.5 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	3420	3505	28771	29419	2905	32324	-3355
1.00	3517	3602	30664	31675	2980	34655	-3791
2.00	3658	3743	33810	34506	3103	37609	-3873
3.00	3823	3907	37627	38899	3278	42178	-4151
4.00	4005	4090	43170	44184	3511	47695	-4516
5.00	4202	4286	49676	50328	3805	54132	-4457

VERTICAL FORCE = 8583.51 KN
EST.PLATFORM LENGTH = 14.17 M

H= 2 M

V M/S	R(S) KN	R(S+A) KN	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	5075	5392	42690	45252	4609	49861	-7170
1.00	5215	5532	45363	48156	4729	52885	-7522
2.00	5420	5737	49401	52501	4907	57409	-8008
3.00	5666	5976	54062	57627	5148	62775	-8094
4.00	5925	6241	61408	64864	5457	69541	-8132
5.00	6211	6527	69062	71473	5863	77817	-8750

VERTICAL FORCE = 10389.72 KN
EST.PLATFORM LENGTH = 16.44 M

SHIP CHARACTERISTICS
LWL = 240.0 M
BWL = 40.0 M
BAC = 40.0 M
HULL2

TABLE 12

H= 1 M

V M/S	P(S) KW	P(S+A) KW	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	3052	3302	32097	19572	1524	21096	11001
1.00	3359	3440	34930	21566	1566	23131	11207
2.00	4117	2930	36061	24583	1645	26228	11833
3.00	4301	2782	42452	26561	1766	28327	13125
4.00	4505	2935	47884	32154	1933	35386	12498
5.00	4725	3205	54879	39089	2149	41787	13092

VERTICAL FORCE = 4964.25 KN
EST.PLATFORM LENGTH = 11.62 M

H= 1.5 M

V M/S	P(S) KW	P(S+A) KW	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	7282	4148	56579	34748	2905	37653	21930
1.00	7365	4323	63620	37631	2980	40611	22010
2.00	7553	4090	68038	42005	3103	45107	22961
3.00	7645	4902	74107	47924	3278	51203	22955
4.00	8190	5247	82941	55049	3511	58560	23911
5.00	8563	5530	91648	63474	3805	67279	24369

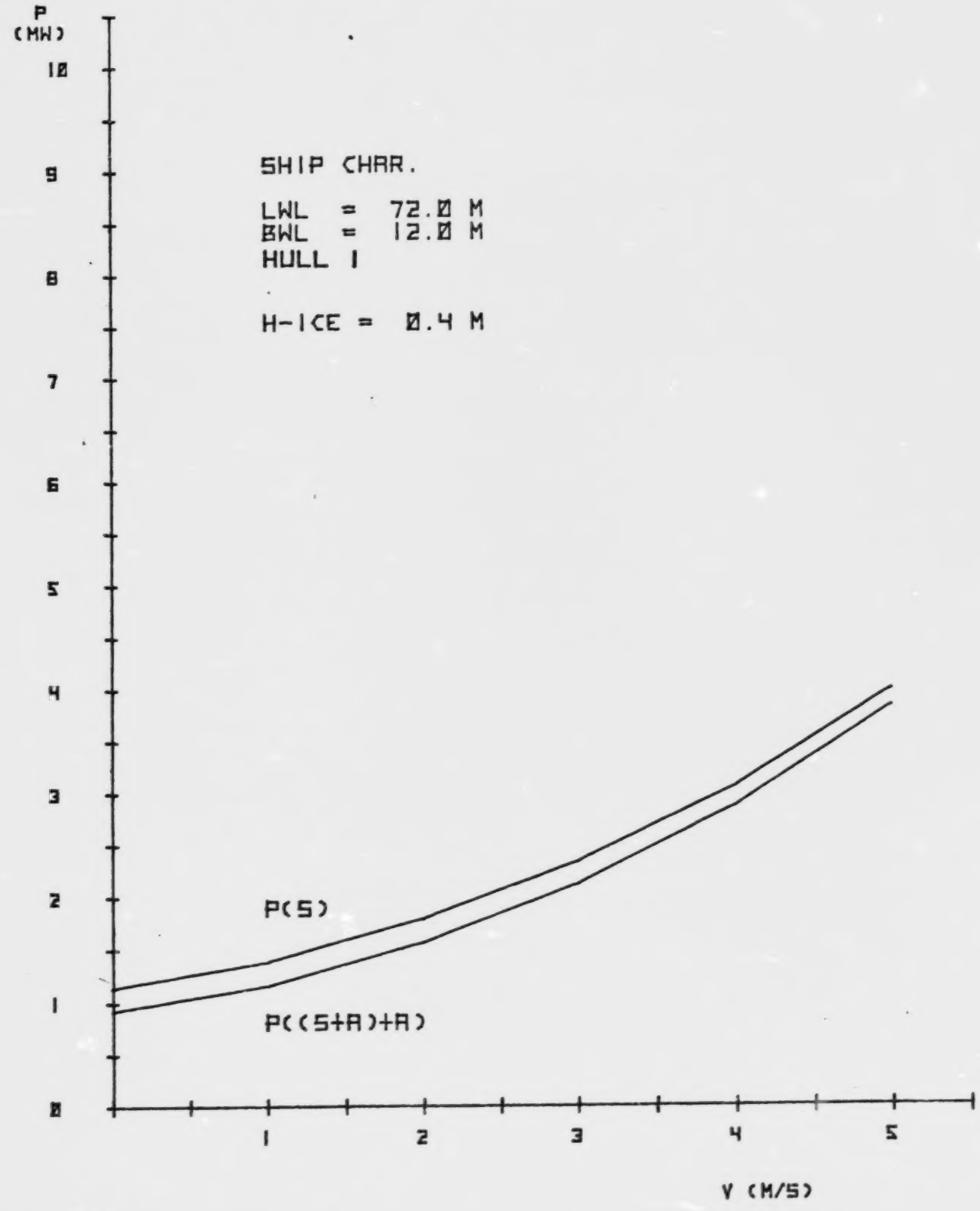
VERTICAL FORCE = 8593.51 KN
EST.PLATFORM LENGTH = 14.17 M

H= 2 M

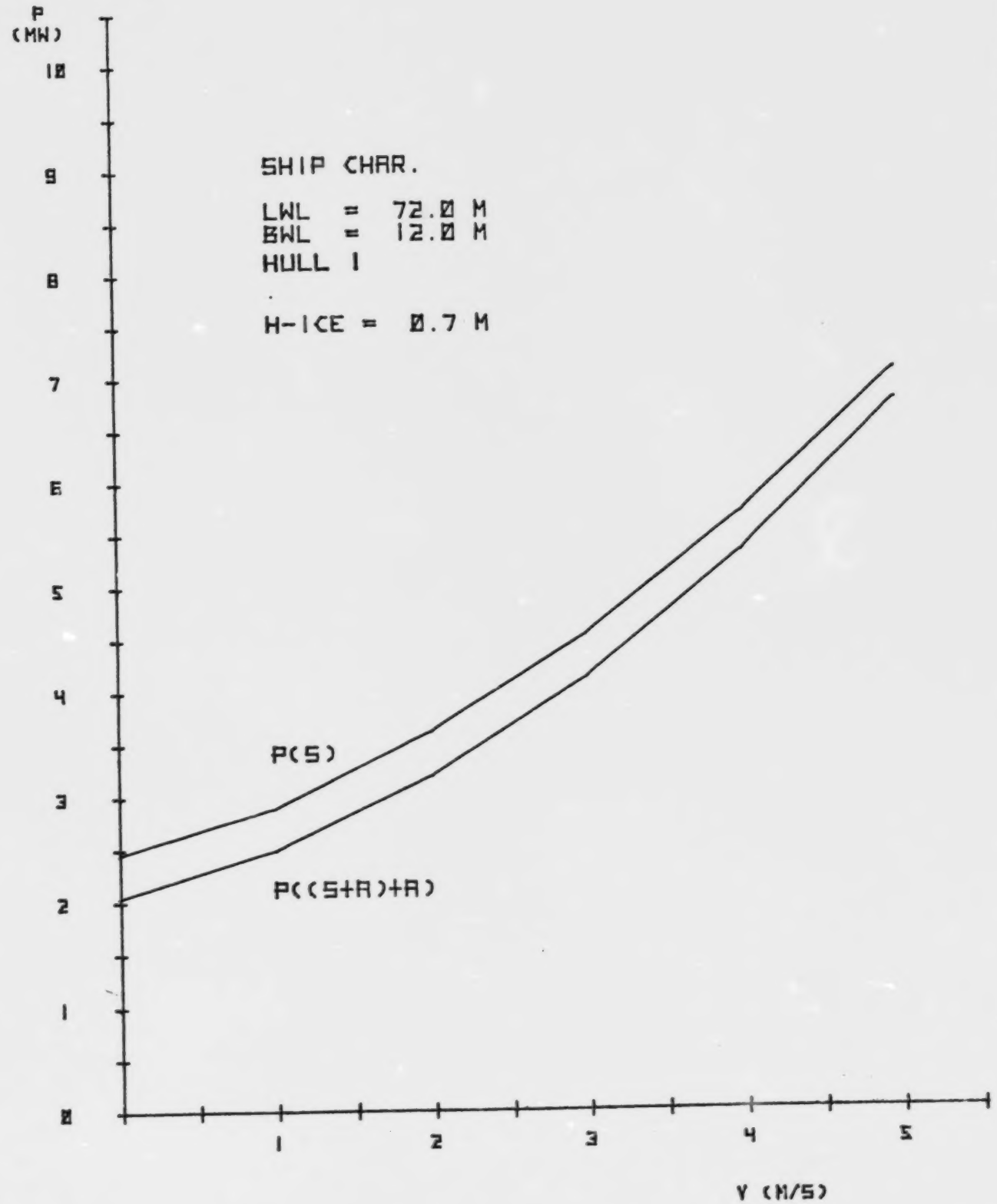
V M/S	P(S) KW	P(S+A) KW	P(S) KW	P(S+A) KW	P(A) KW	P((S+A)+A) KW	DIF KW
0.00	11134	6316	93370	53006	4609	57615	35955
1.00	11380	6581	98176	57291	4729	62020	36156
2.00	11778	6959	104398	63047	4907	67754	37141
3.00	12091	7423	111478	70314	5148	76062	37013
4.00	12783	7925	124017	79956	5457	85412	38605
5.00	13279	8466	137069	90711	5839	96550	39310

VERTICAL FORCE = 12898.11 KN
EST.PLATFORM LENGTH = 16.44 M

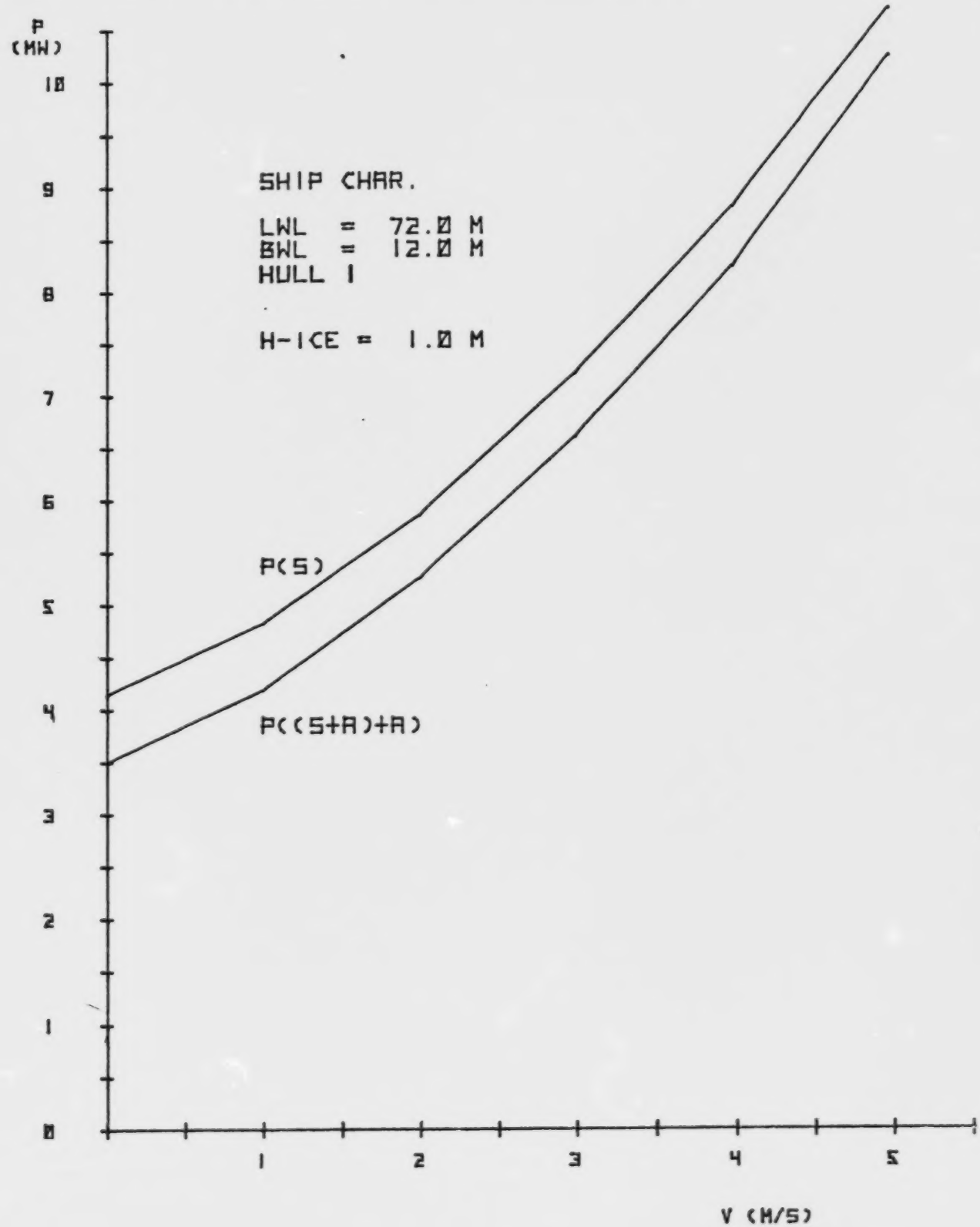
WADAM	ACIB-STUDY	FIG. 1
	POWER AS FUNCTION OF SPEED	



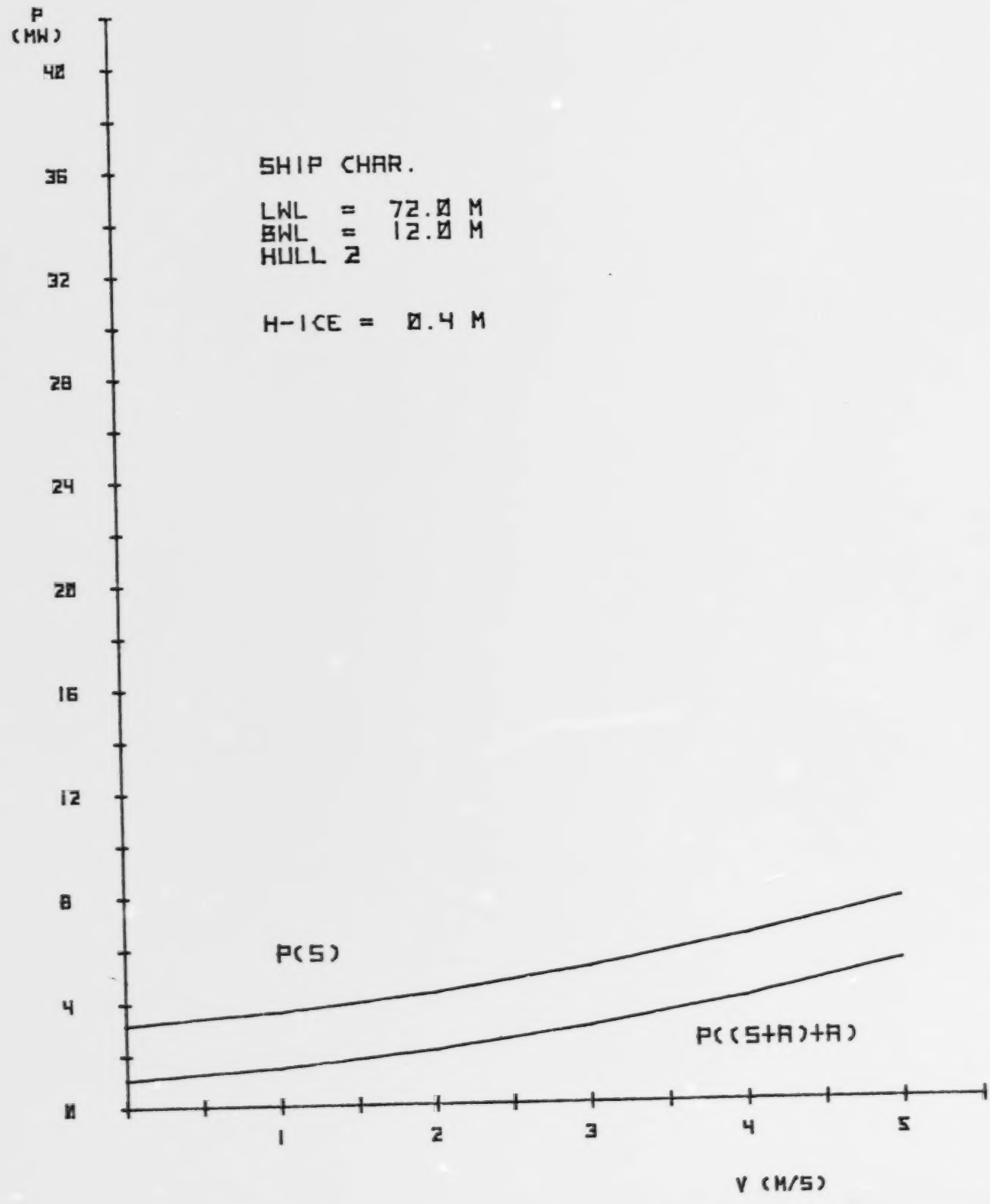
WADAM	RCIB-STUDY	FIG. 2
	POWER AS FUNCTION OF SPEED	



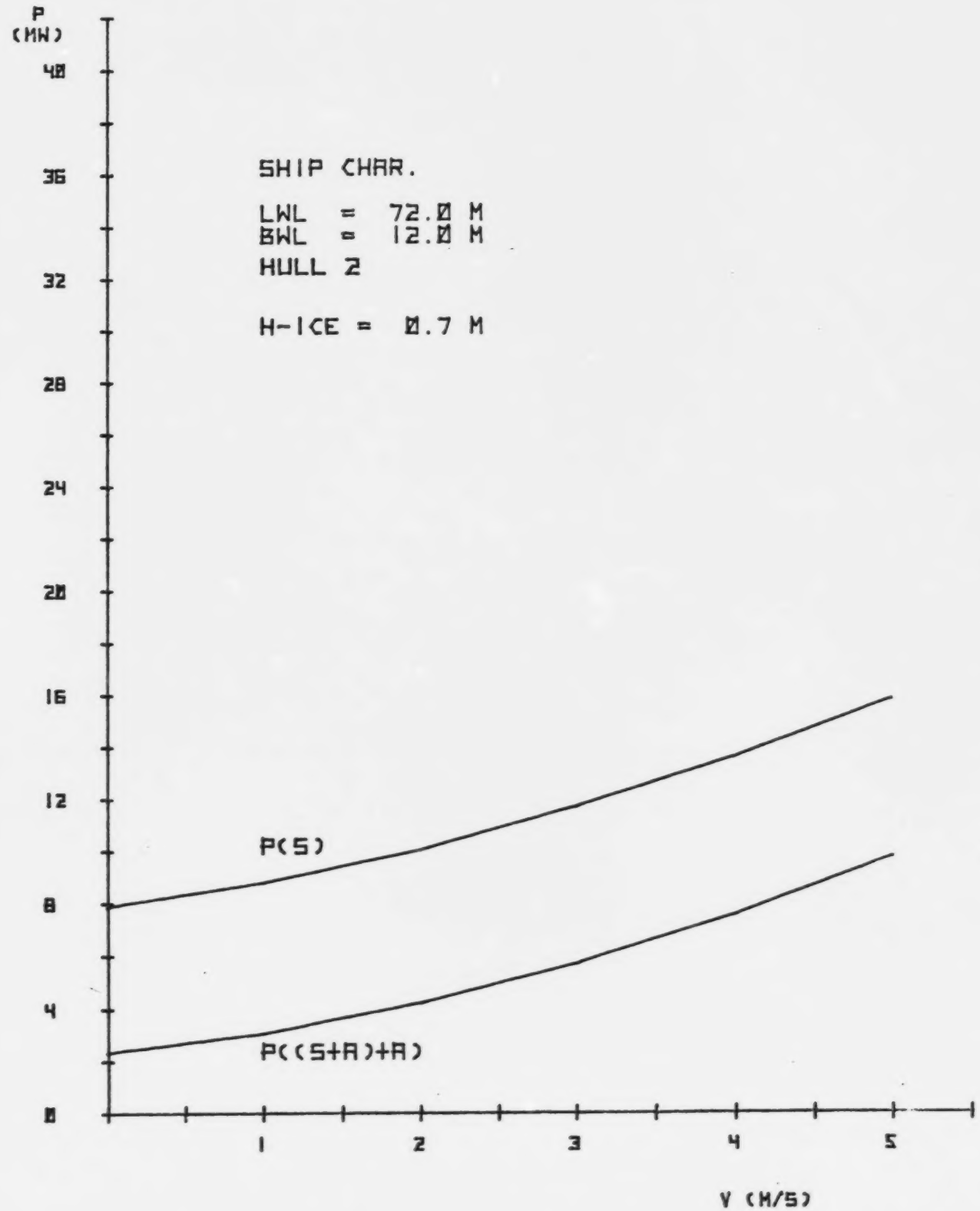
WADAM	ACIB-STUDY	FIG. 3
	POWER AS FUNCTION OF SPEED	



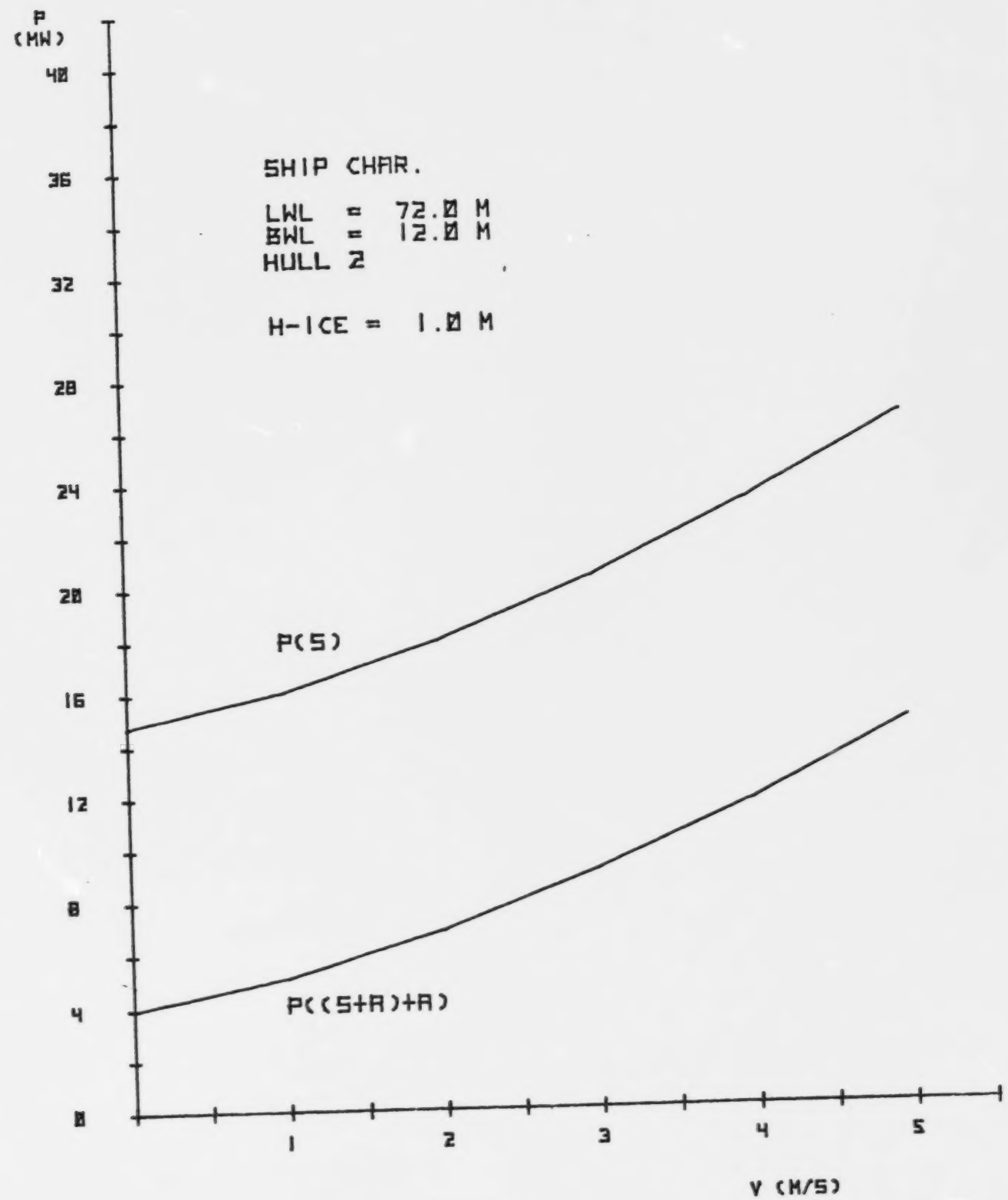
WADAM	ACIB-STUDY	FIG. 4
	POWER AS FUNCTION OF SPEED	



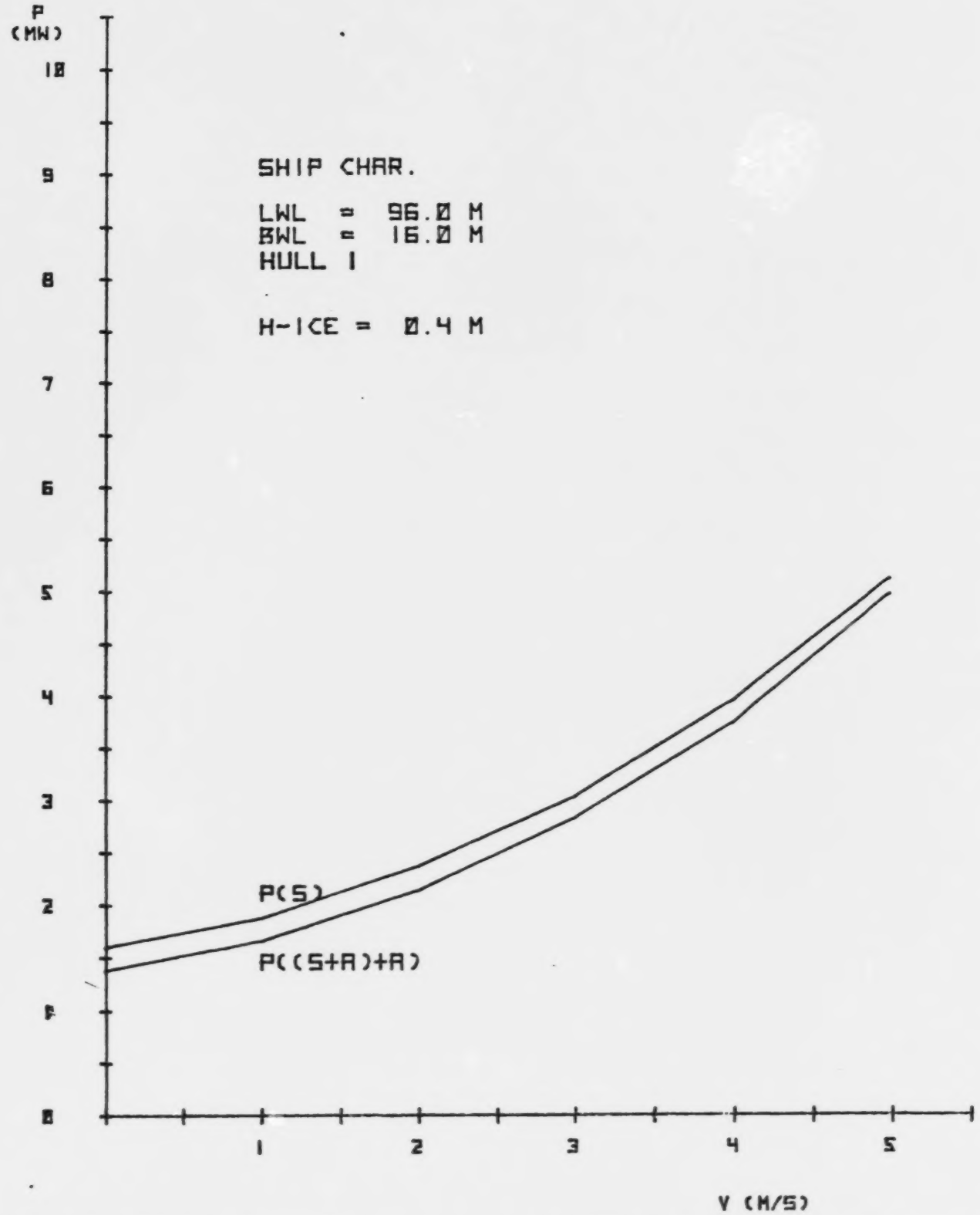
WADAM	ACIB-STUDY	FIG. 5
	POWER AS FUNCTION OF SPEED	



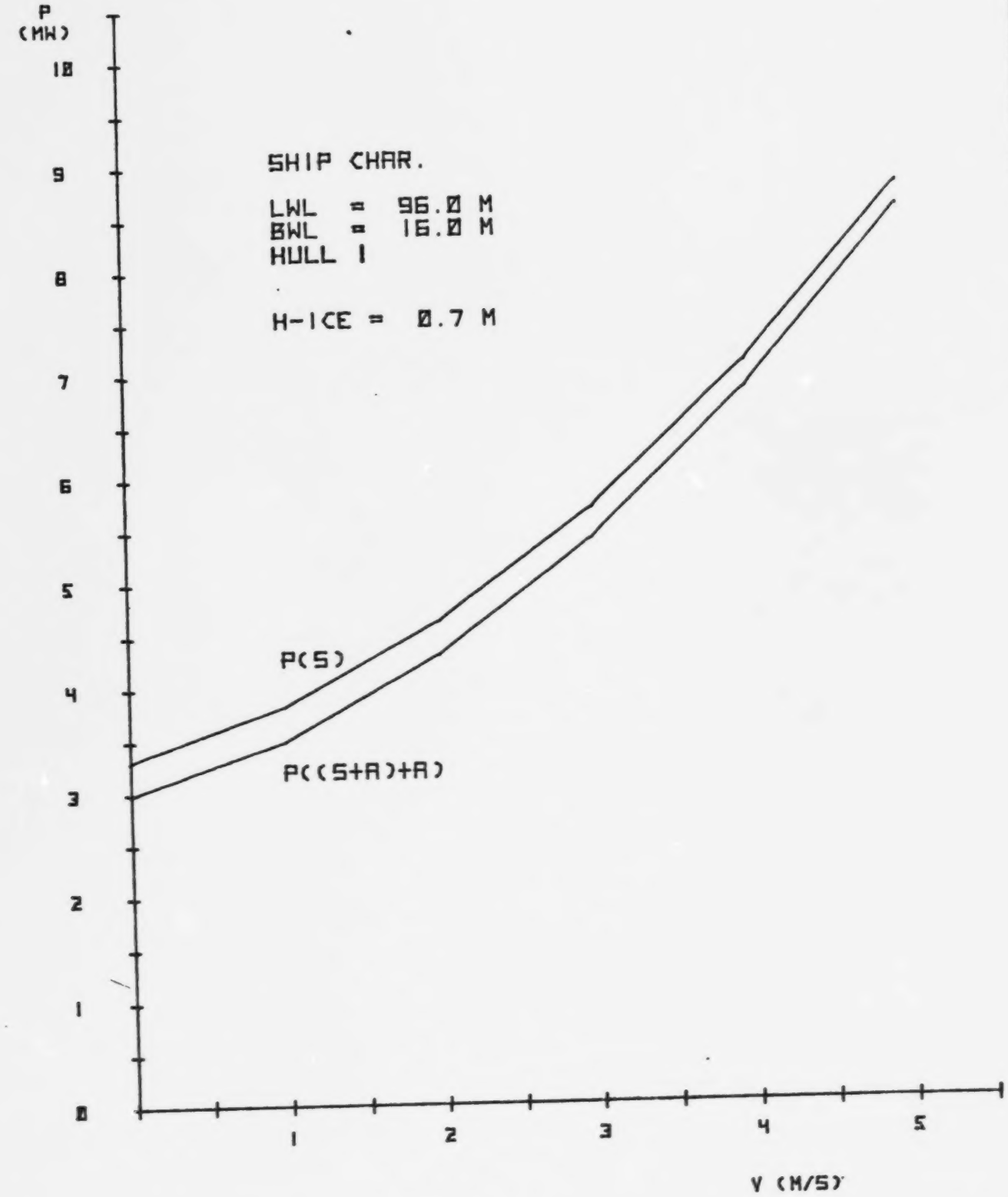
WADAM	ACIB-STUDY	FIG. 6
	POWER AS FUNCTION OF SPEED	



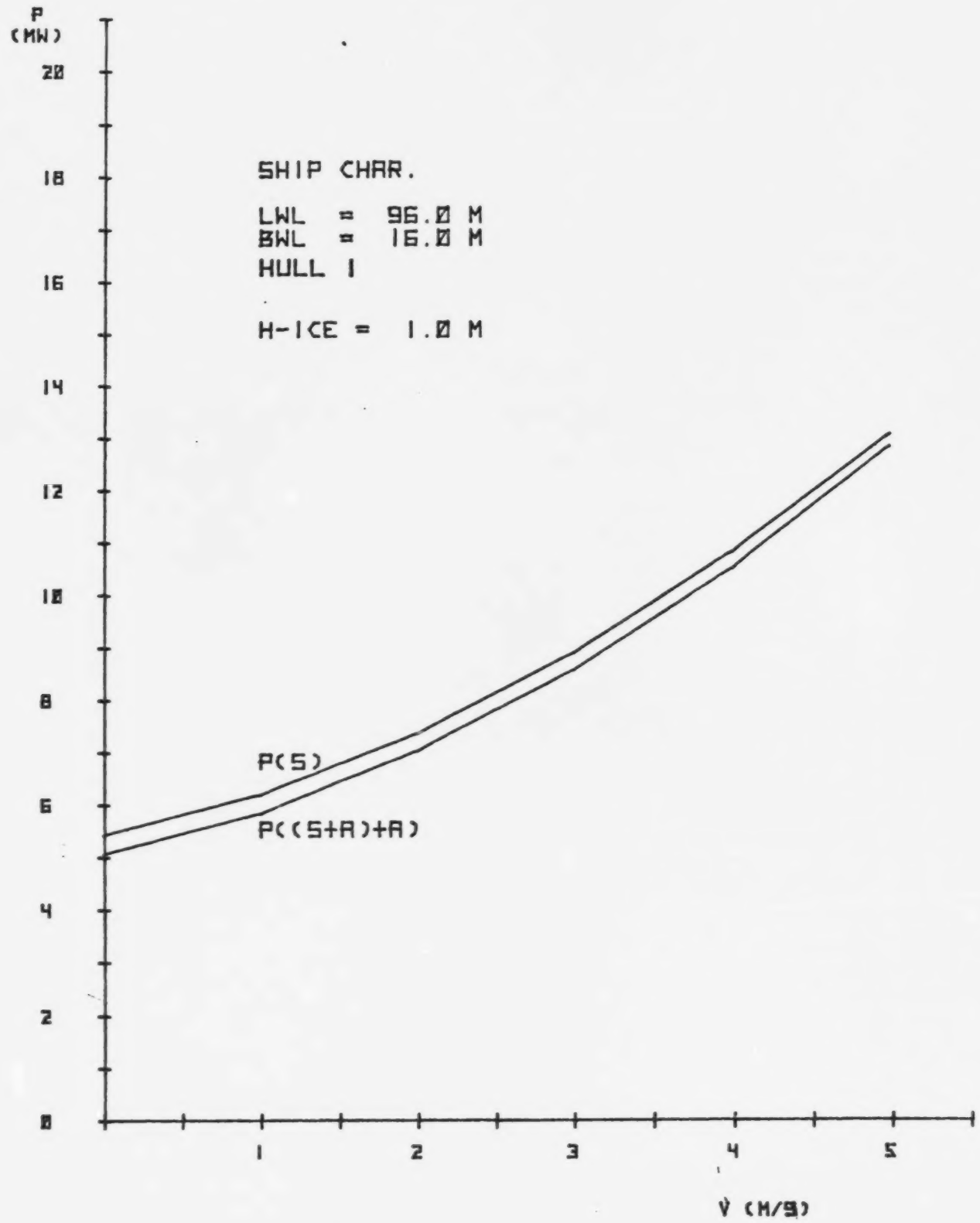
WADAM	ACIB-STUDY	FIG. 7
	POWER AS FUNCTION OF SPEED	



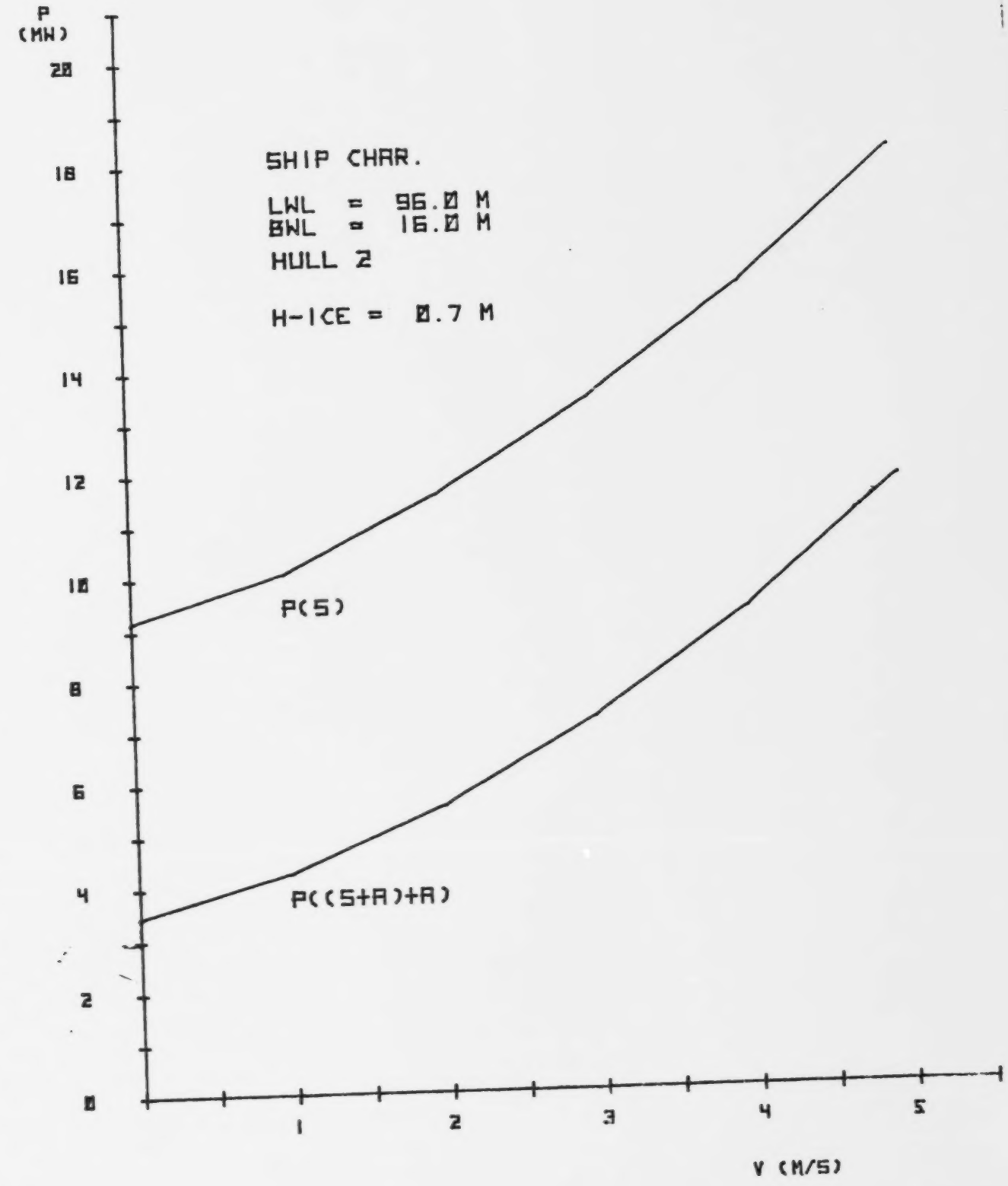
WADAM	ACIB-STUDY	FIG. 8
	POWER AS FUNCTION OF SPEED	



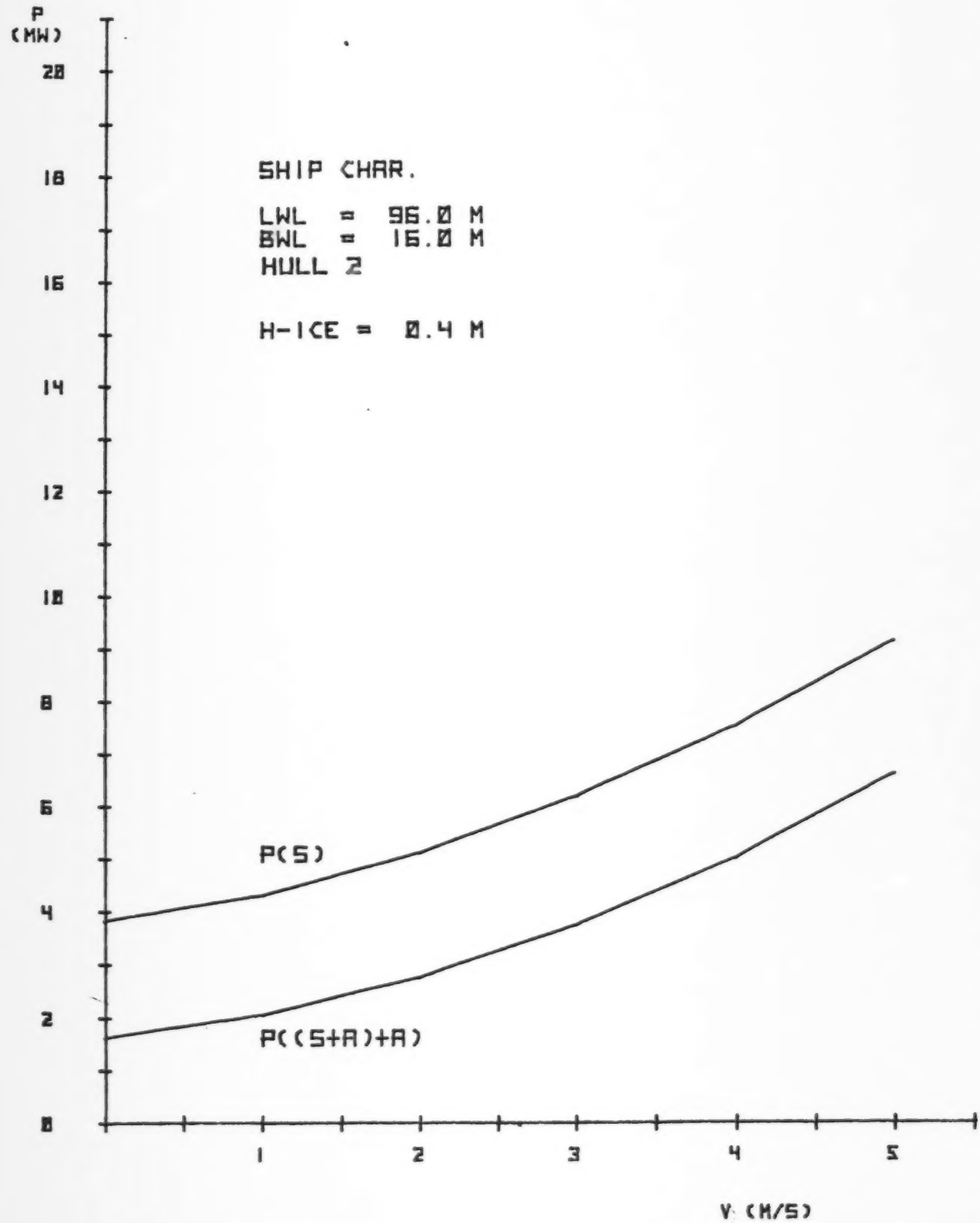
WADAM	ACIB-STUDY	FIG. 9
	POWER AS FUNCTION OF SPEED	



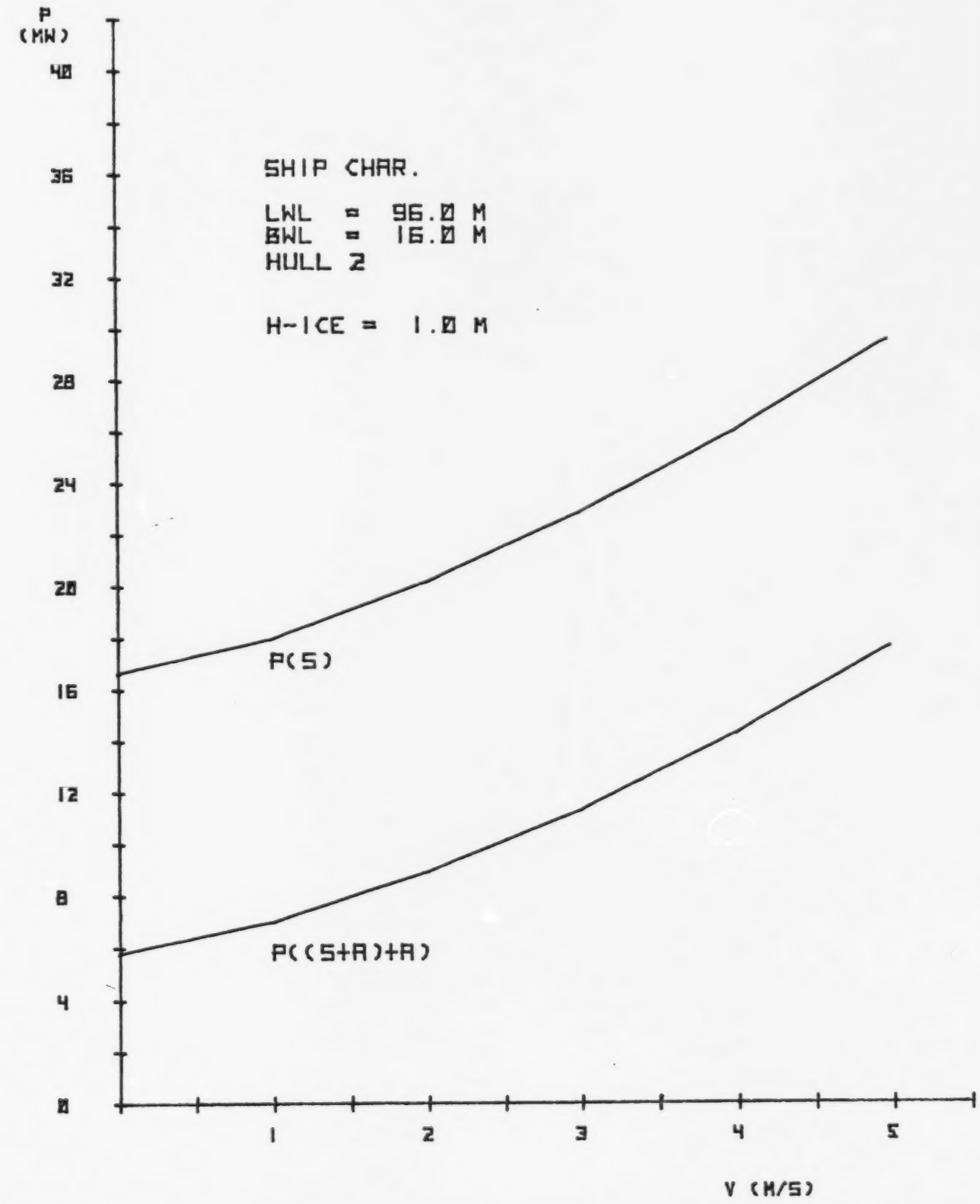
WADAM	ACIB-STUDY	FIG. 10
	POWER AS FUNCTION OF SPEED	



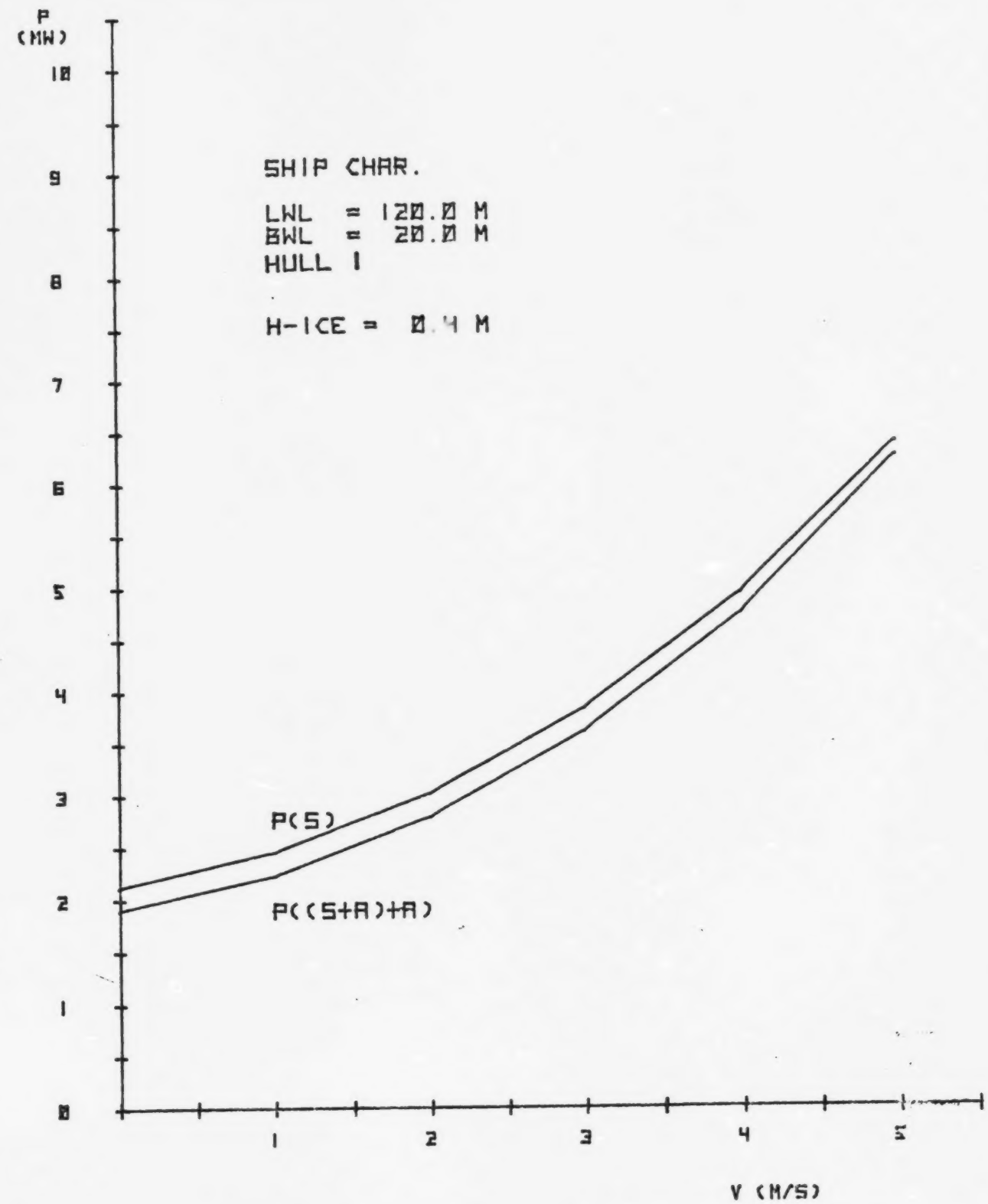
WADAM	ACIB-STUDY	FIG. 11
	POWER AS FUNCTION OF SPEED	



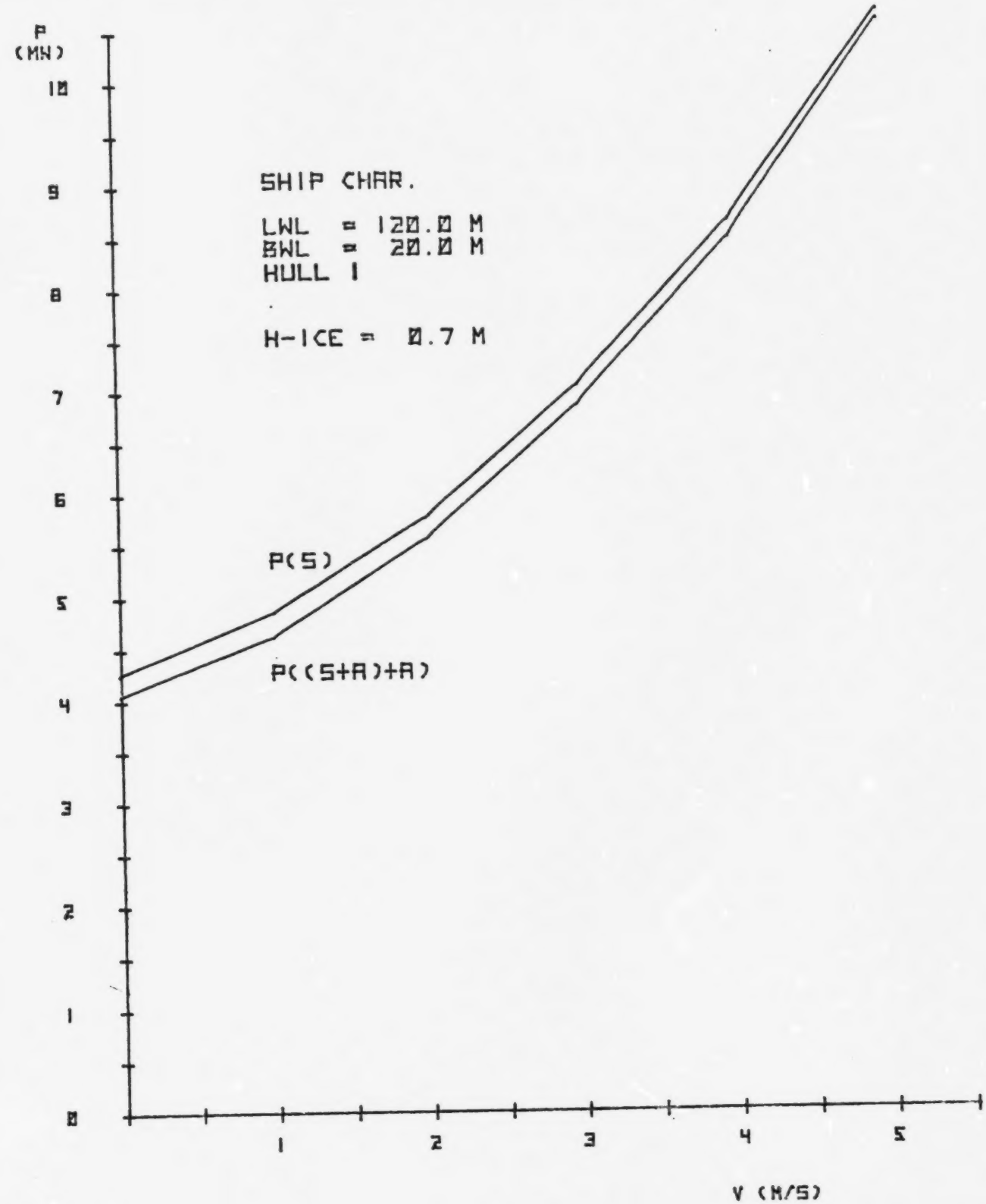
WADAM	ACIB-STUDY	FIG. 12
	POWER AS FUNCTION OF SPEED	



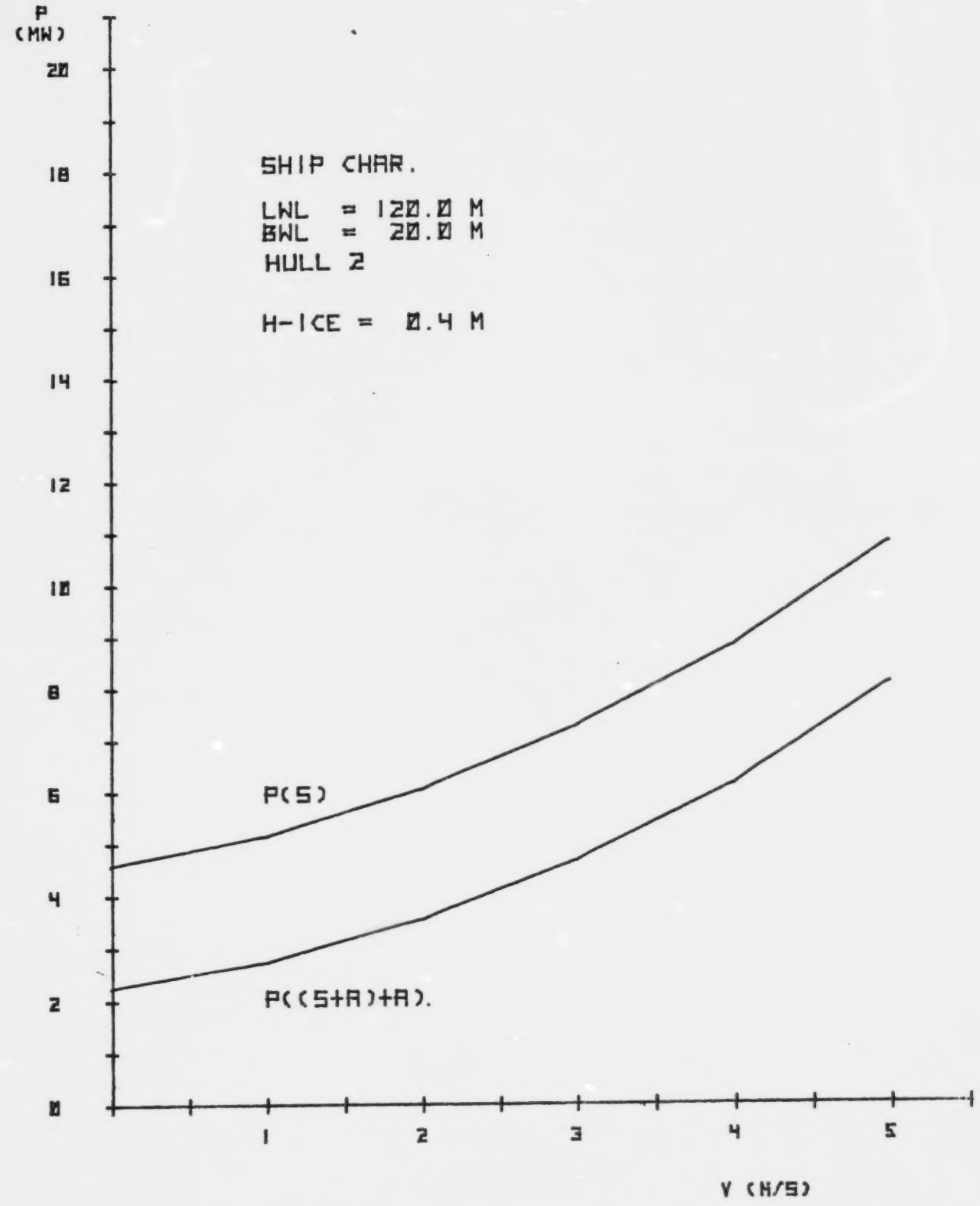
WADAM	RCIB-STUDY	FIG. 13
	POWER AS FUNCTION OF SPEED	



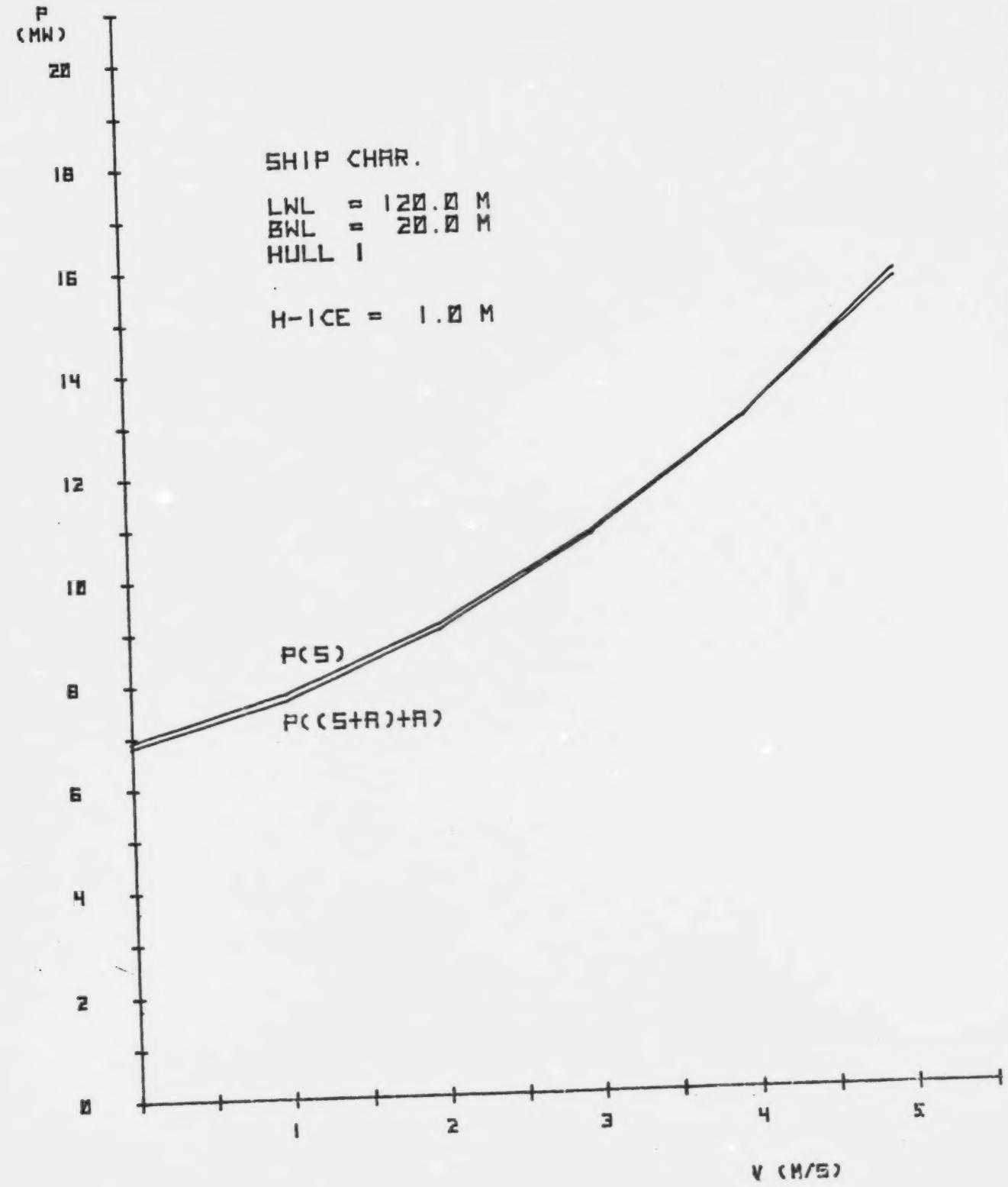
WADAM	ACIB-STUDY	FIG. 14
	POWER AS FUNCTION OF SPEED	



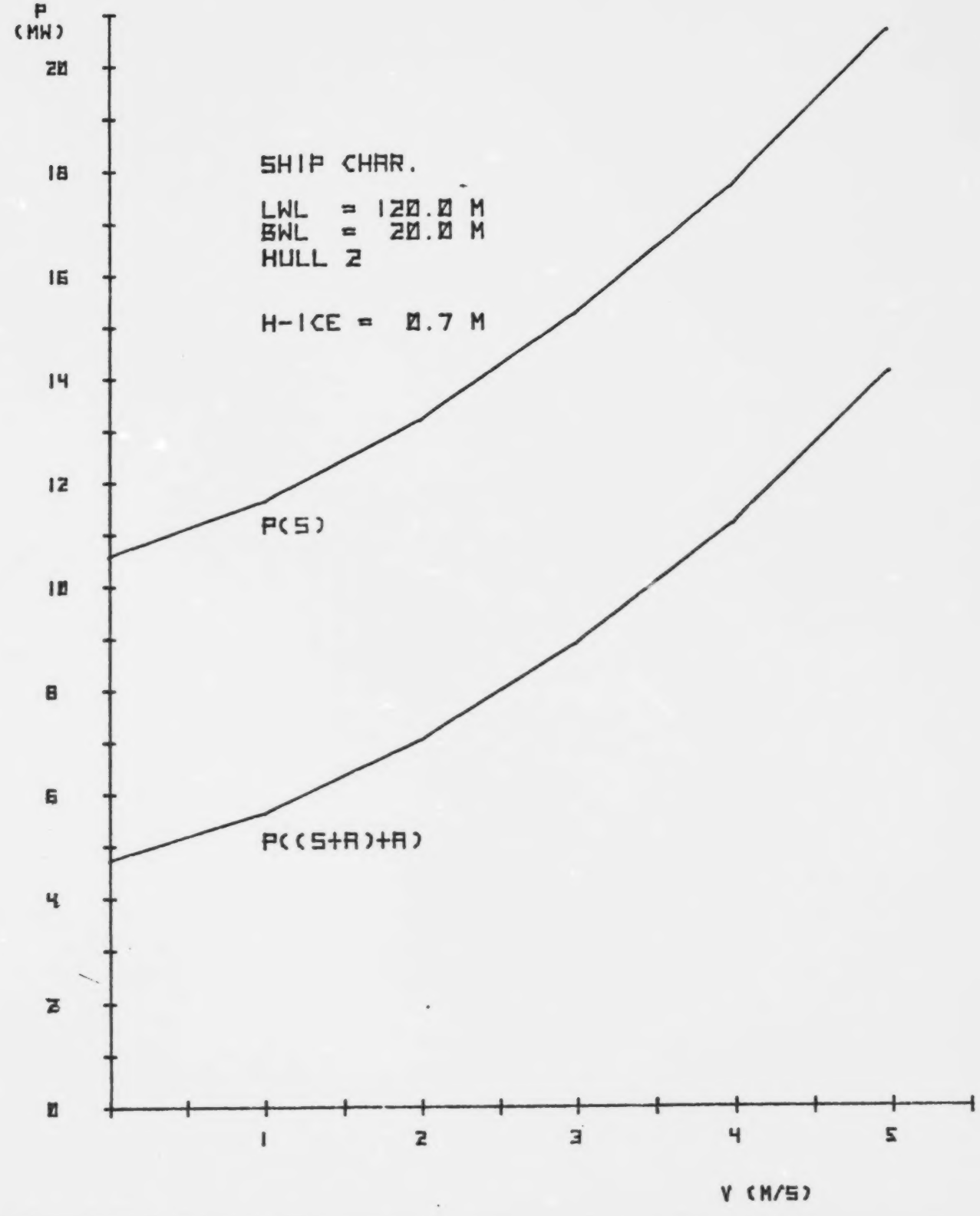
WADAM	RC18-STUDY	FIG. 15
	POWER AS FUNCTION OF SPEED	



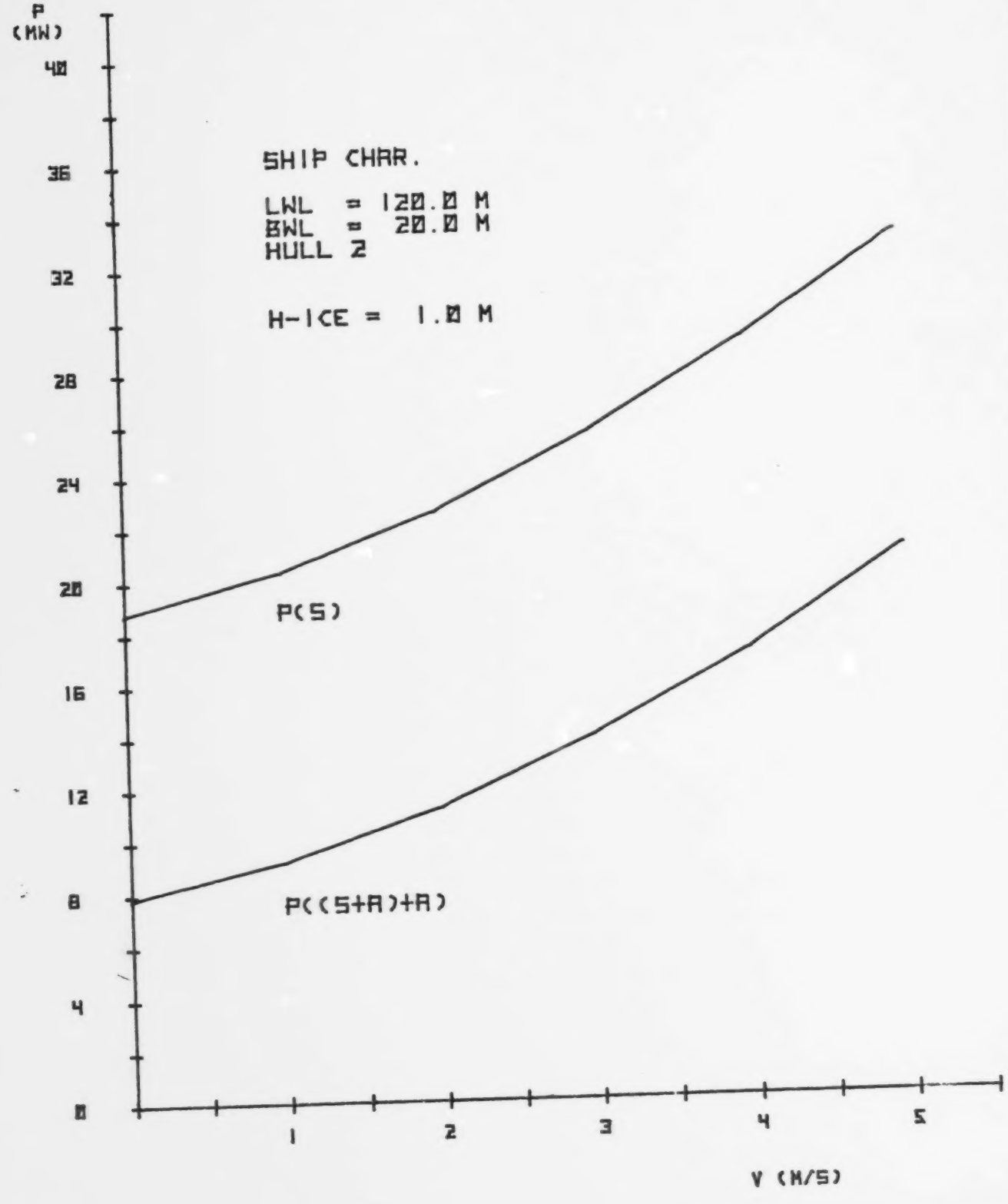
WADAM	ACIB-STUDY	FIG. 16
	POWER AS FUNCTION OF SPEED	



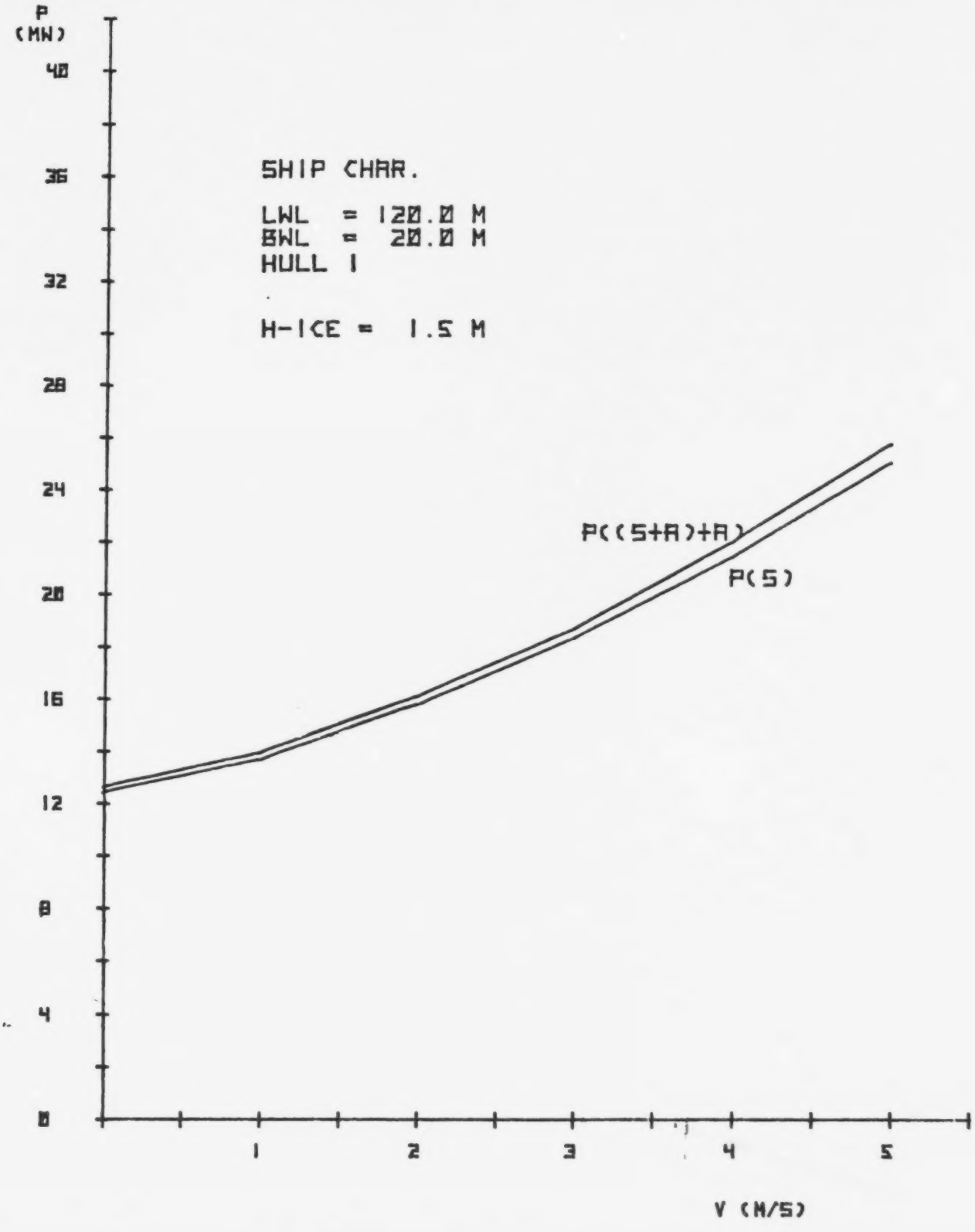
WADAM	ACIB-STUDY	FIG. 17
	POWER AS FUNCTION OF SPEED	



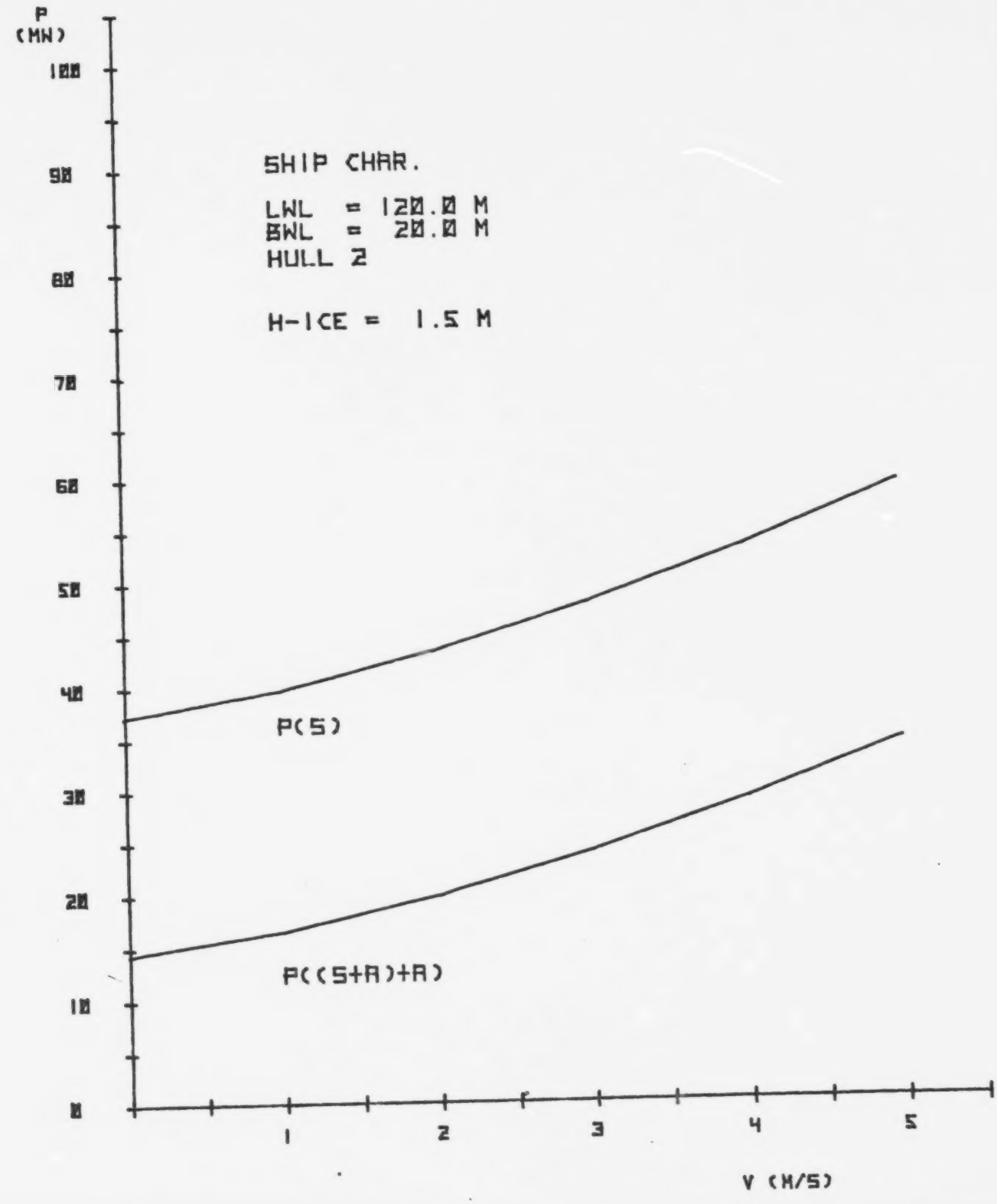
WADAM	ACIB-STUDY	FIG. 18
	POWER AS FUNCTION OF SPEED	



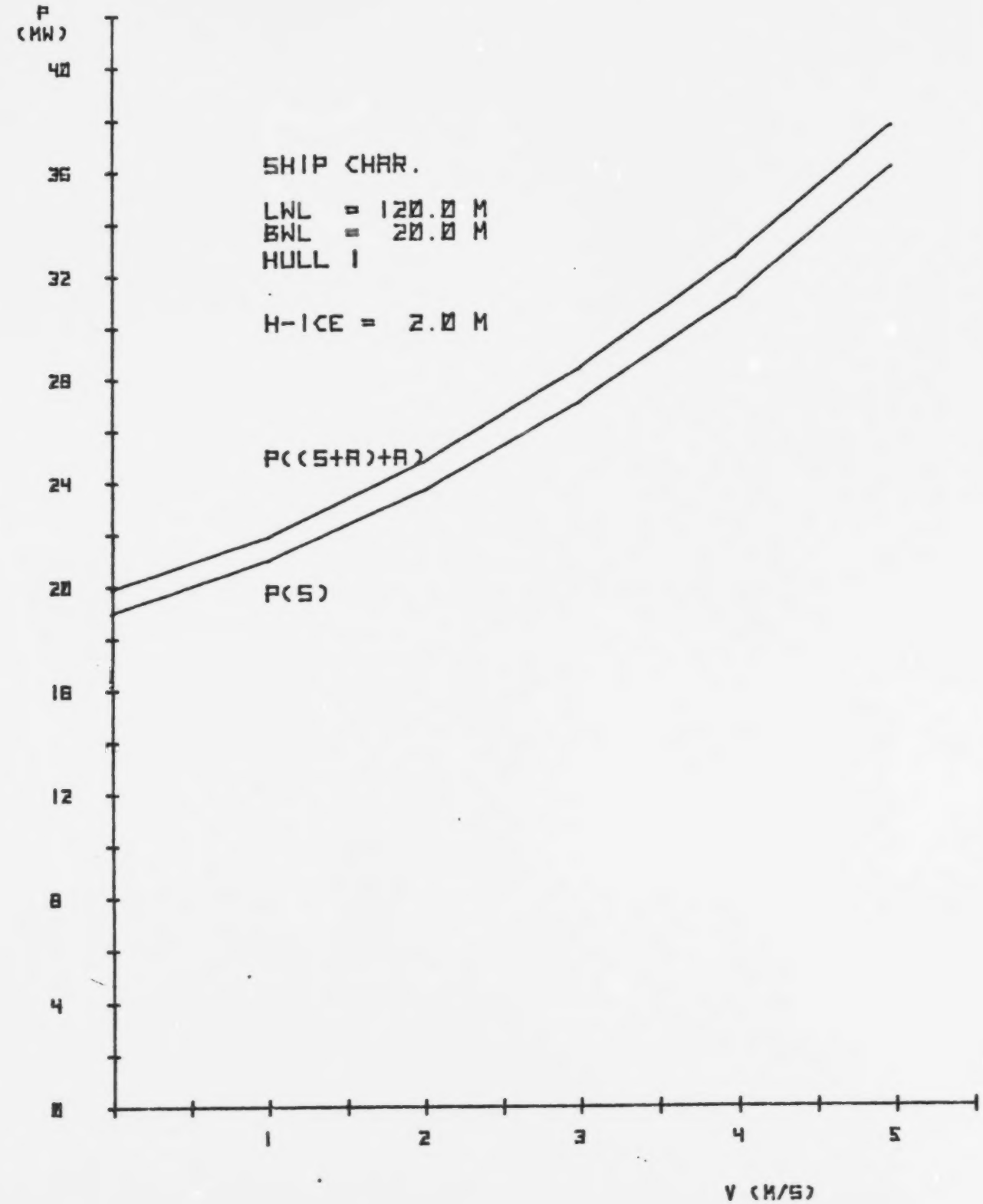
WADAM	ACIB-STUDY	FIG. 19
	POWER AS FUNCTION OF SPEED	



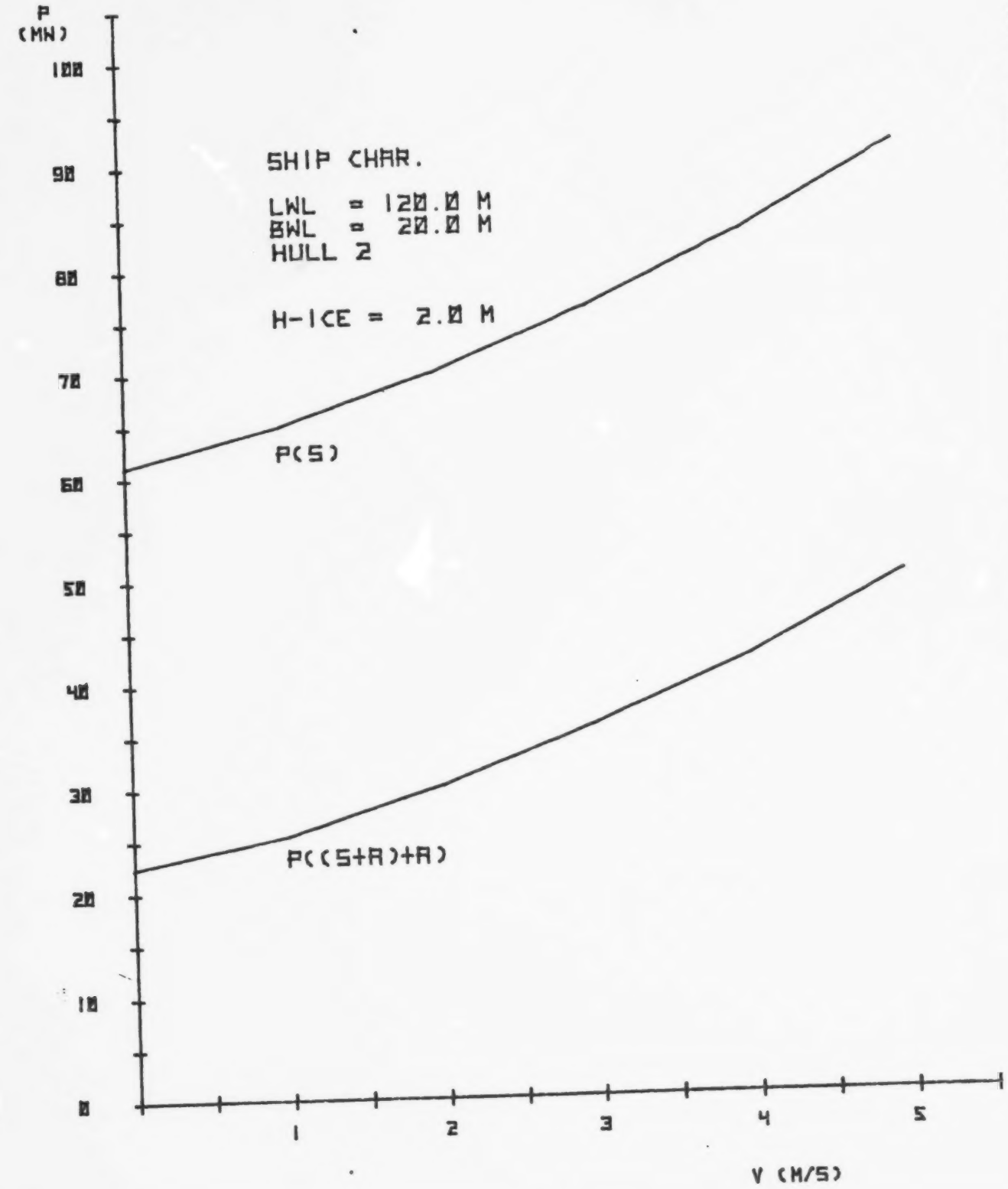
WADAM	RC1B-STUDY	FIG. 20
	POWER AS FUNCTION OF SPEED	



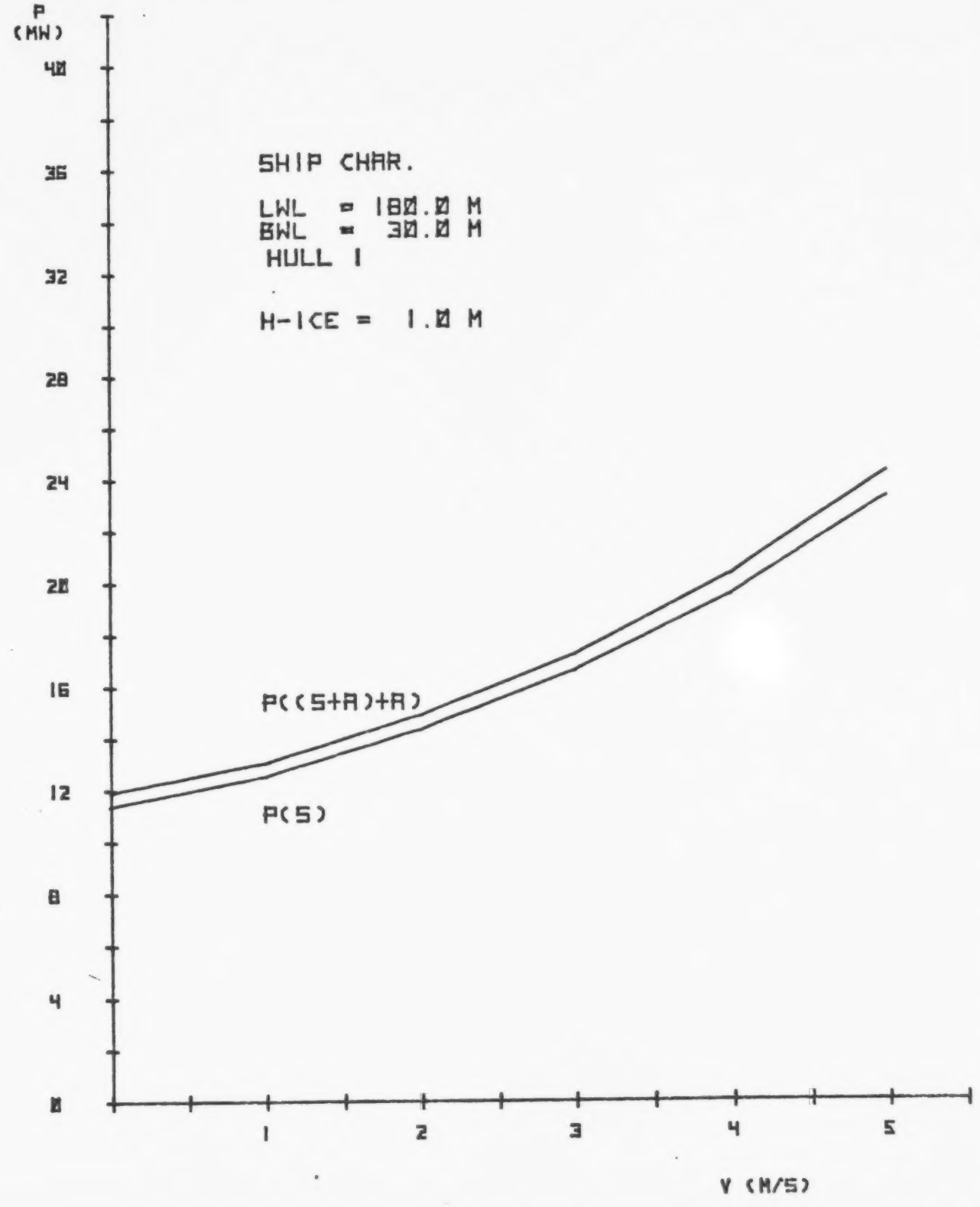
WADAM	ACIB-STUDY	FIG. 21
	POWER AS FUNCTION OF SPEED	



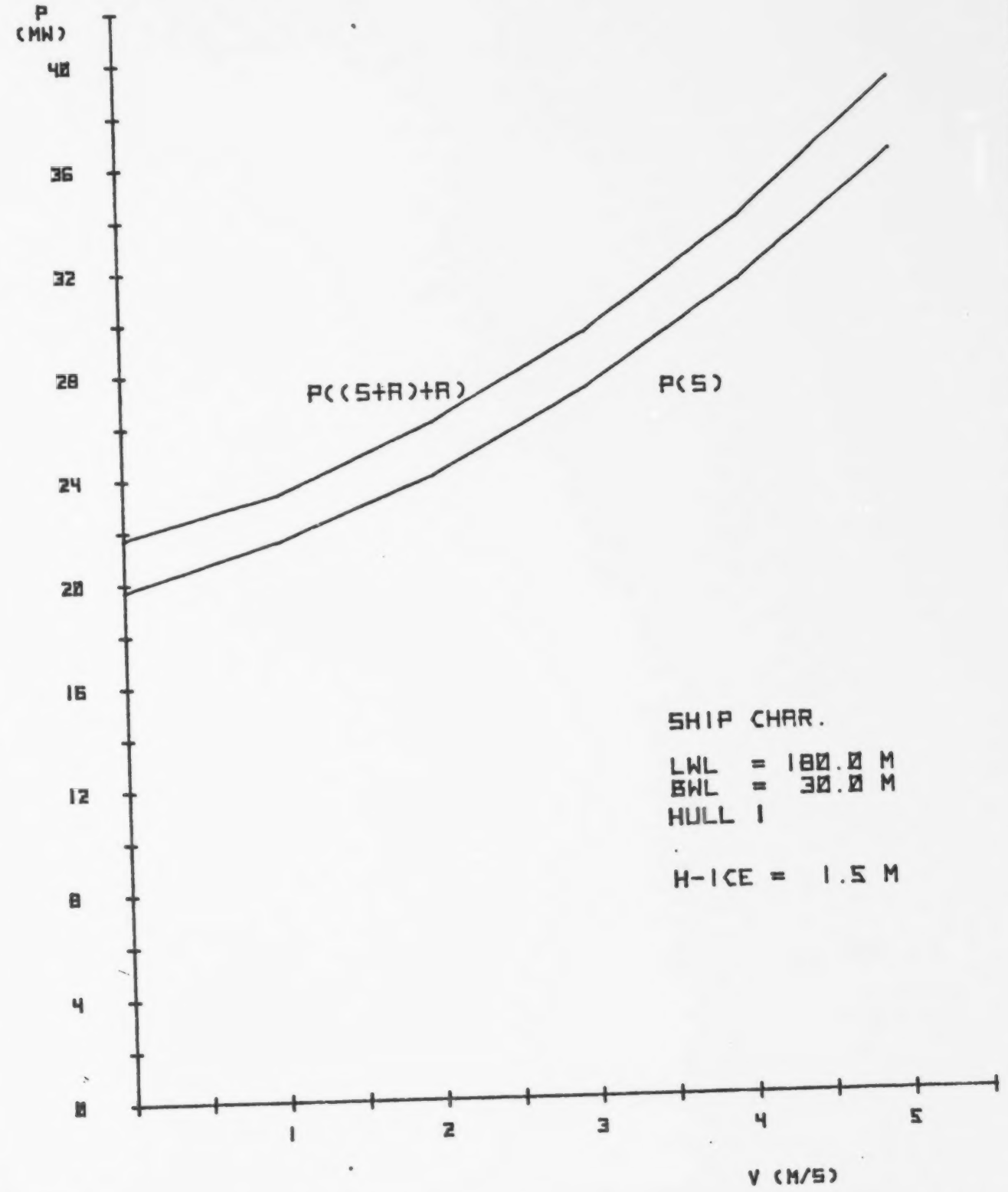
WADAM	ACIB-STUDY	FIG. 22
	POWER AS FUNCTION OF SPEED	



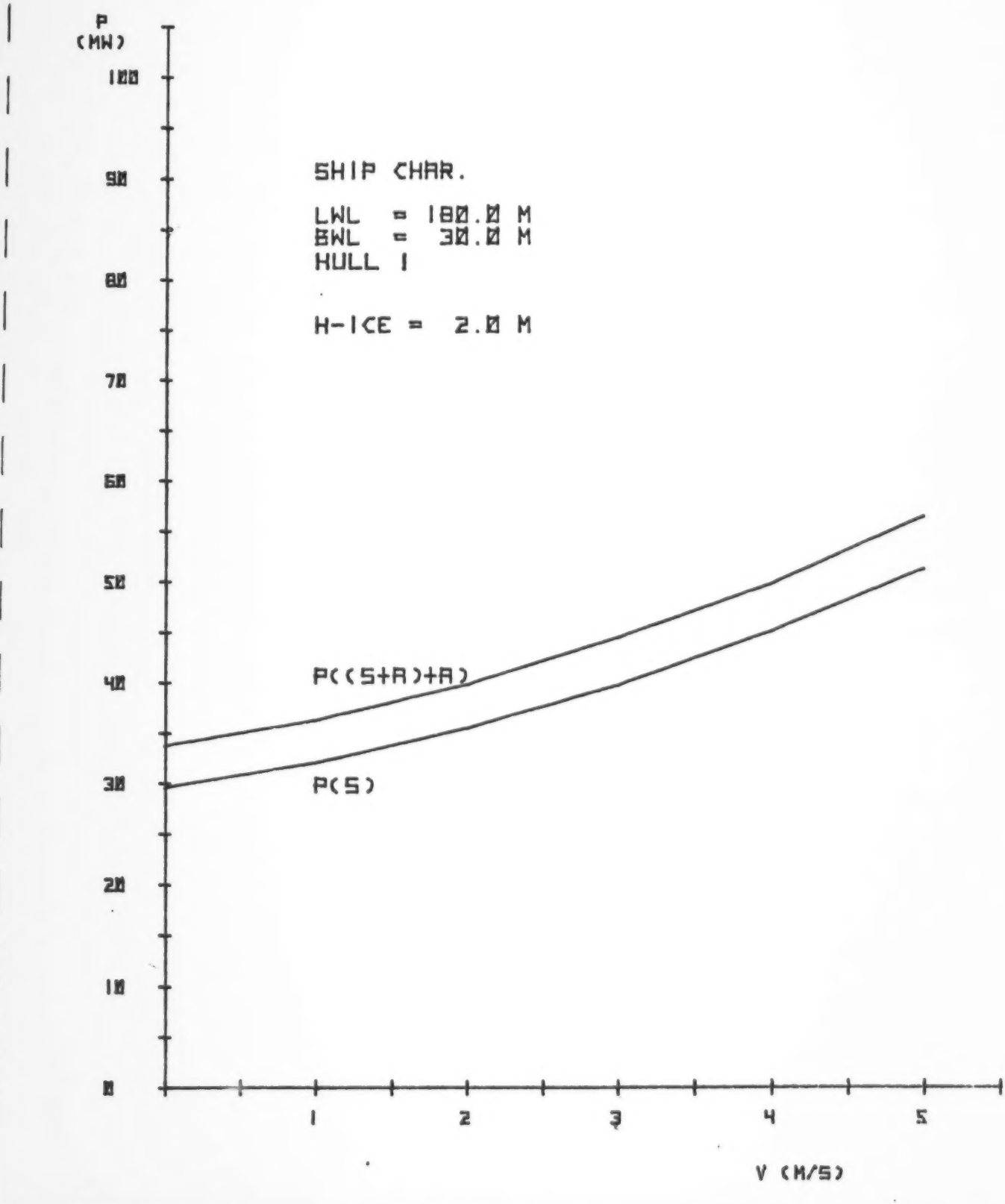
WADAM	RCIB-STUDY	FIG. 23
	POWER AS FUNCTION OF SPEED	



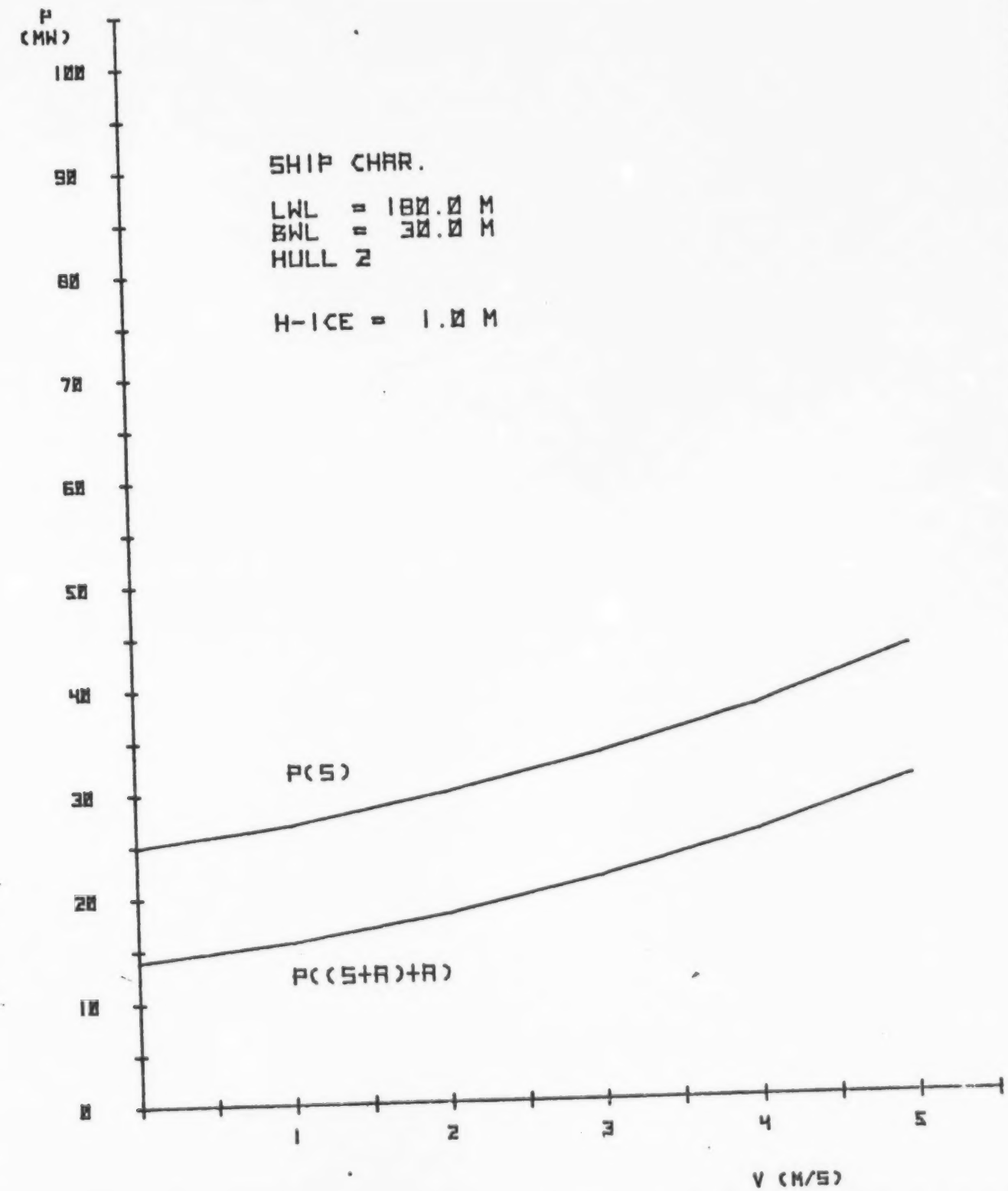
WADAM	RC1B-STUDY	FIG. 24
	POWER AS FUNCTION OF SPEED	



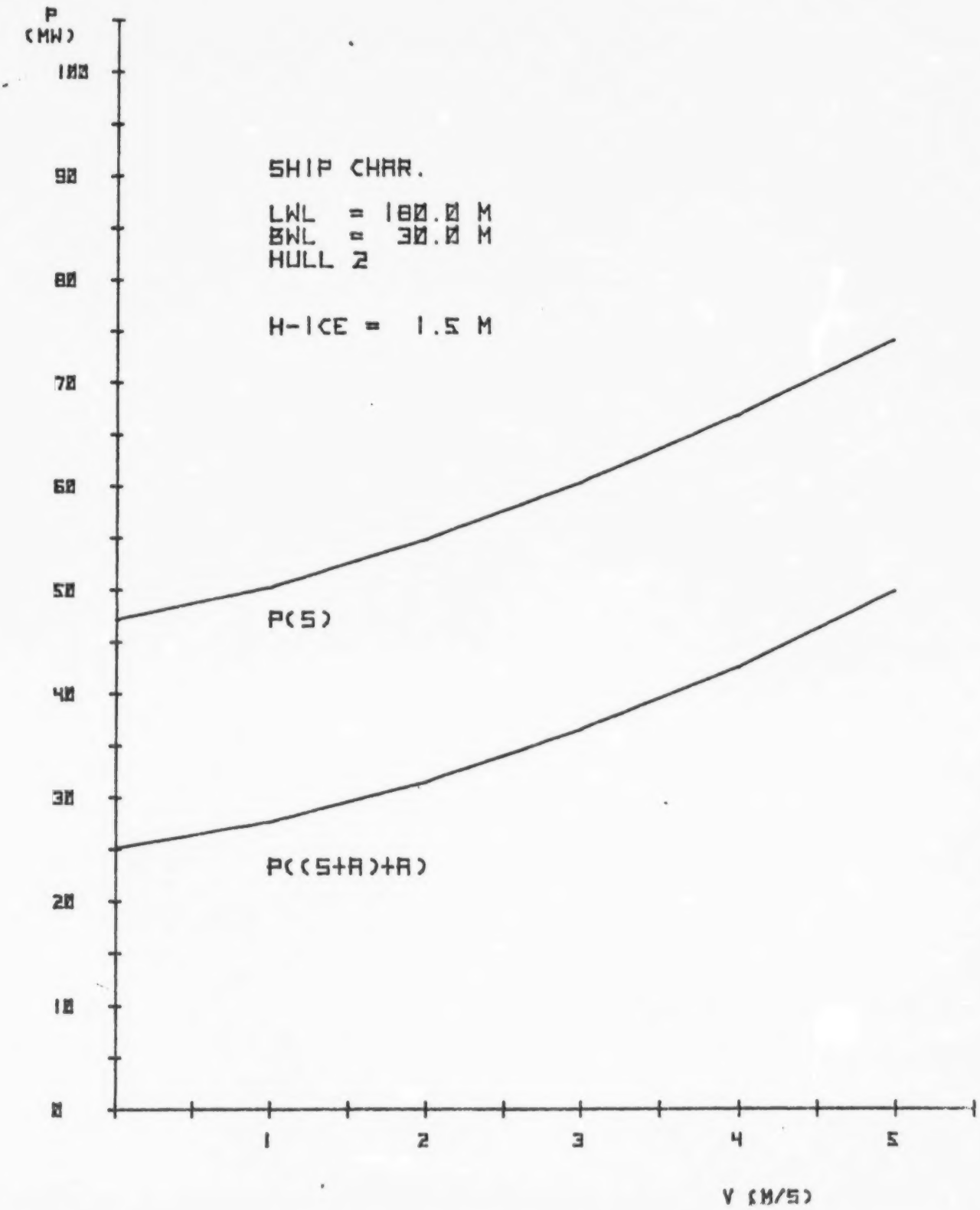
WADAM	RC1B-STUDY	FIG. 25
	POWER AS FUNCTION OF SPEED	



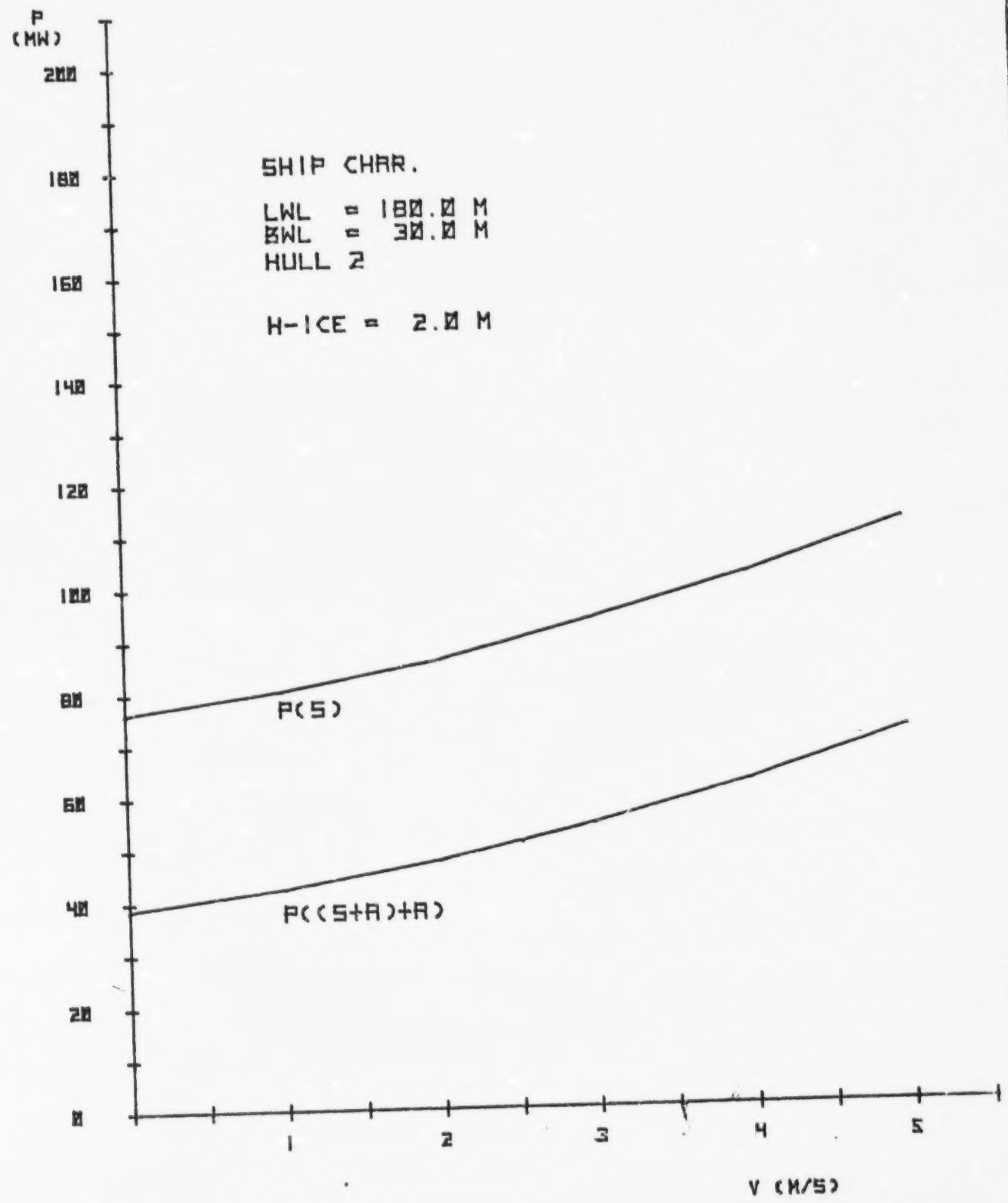
WADAM	AC1B-STUDY	FIG. 26
	POWER AS FUNCTION OF SPEED	



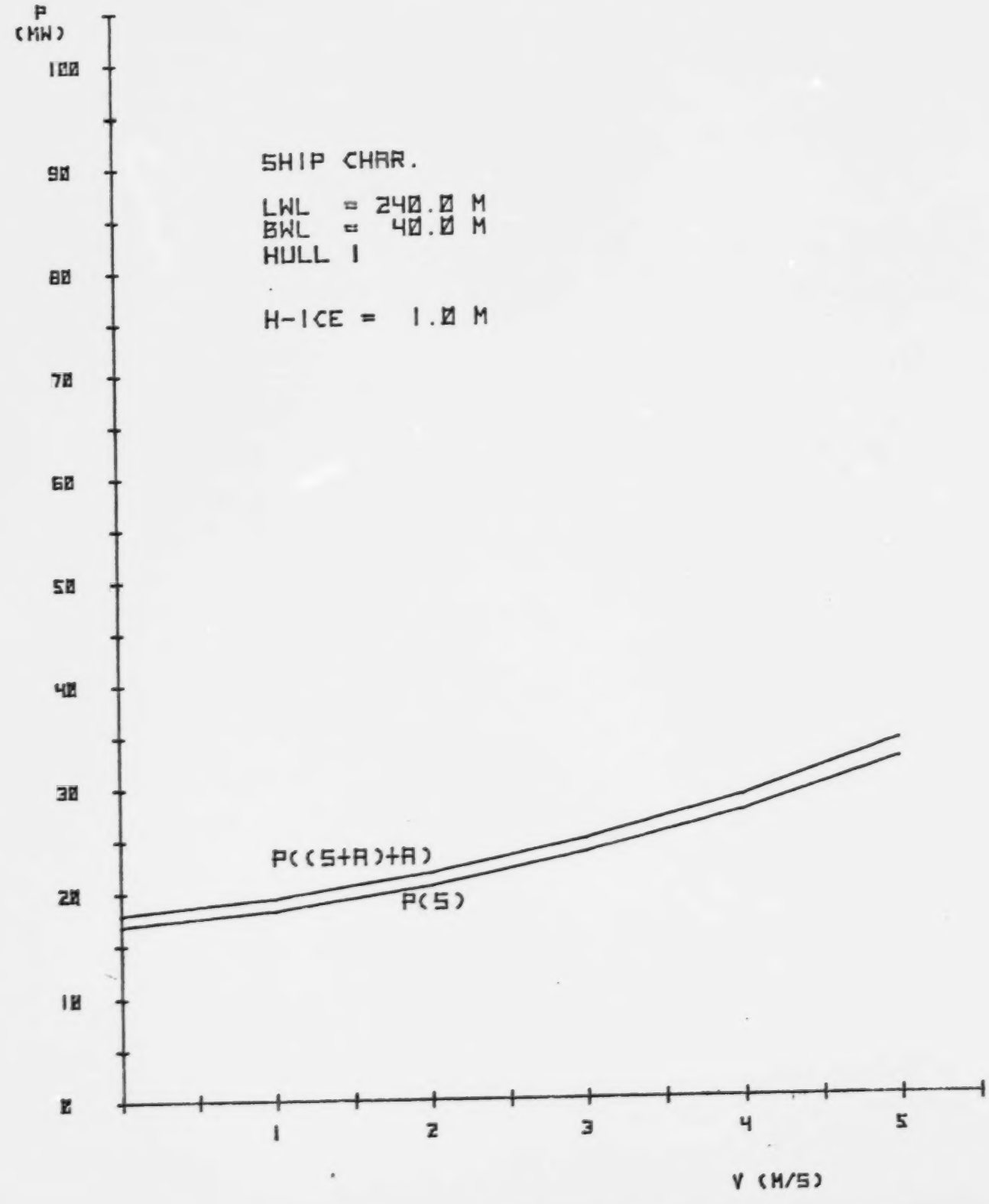
WADAM	RCIB-STUDY	FIG. 27
	POWER AS FUNCTION OF SPEED	



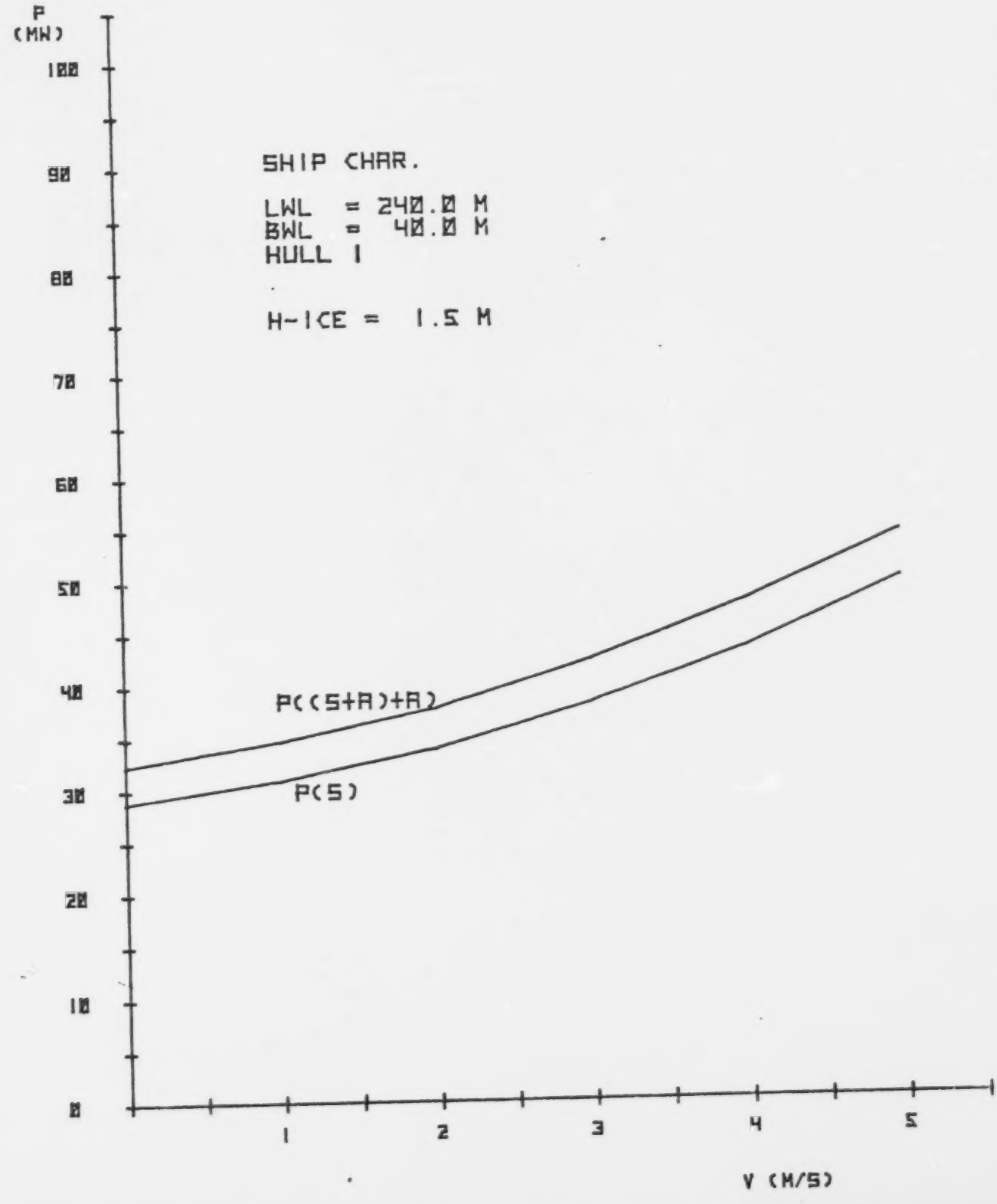
WADAM	ACIB-STUDY	FIG. 28
	POWER AS FUNCTION OF SPEED	



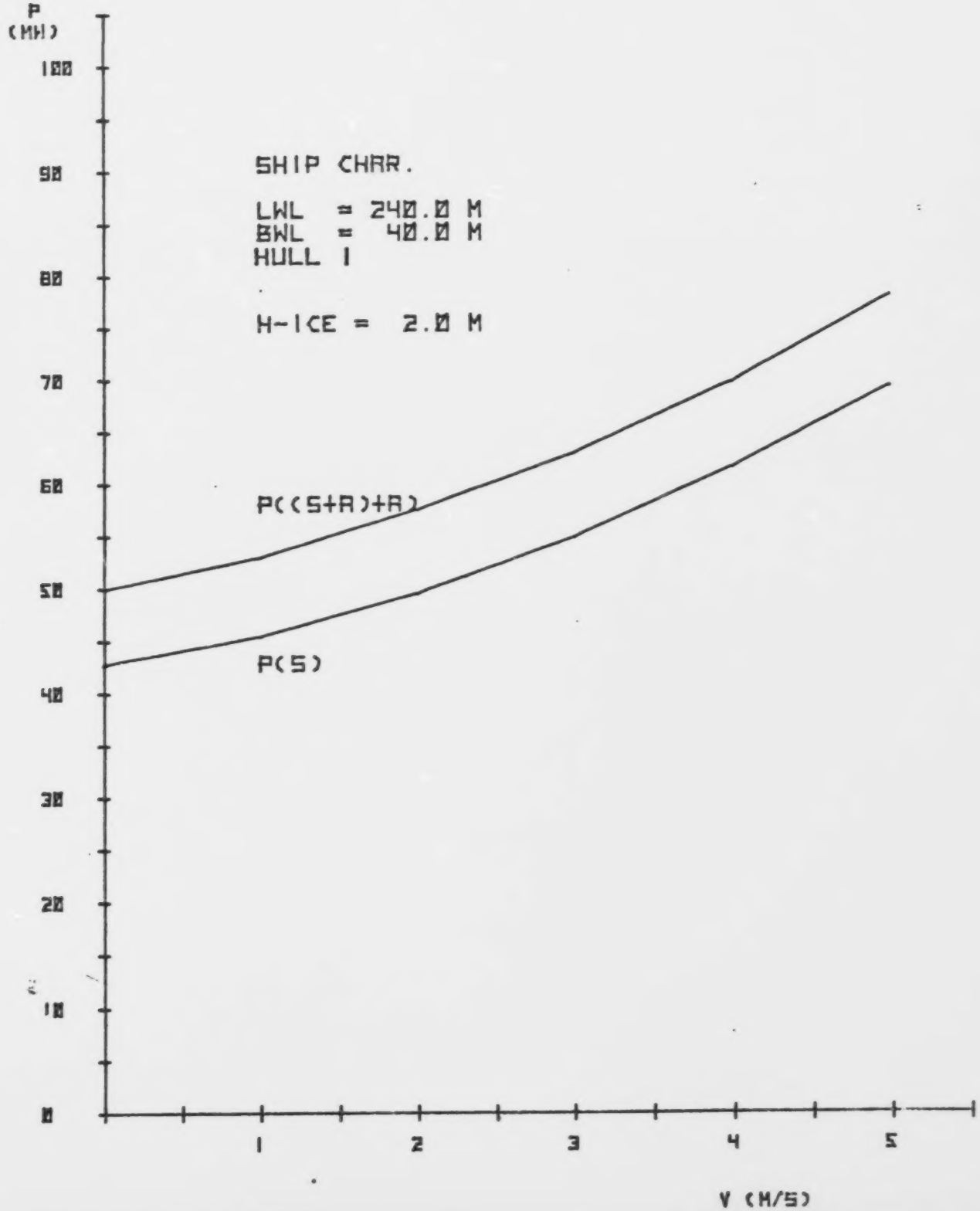
WADAM	ACIB-STUDY	FIG. 29
	POWER AS FUNCTION OF SPEED	



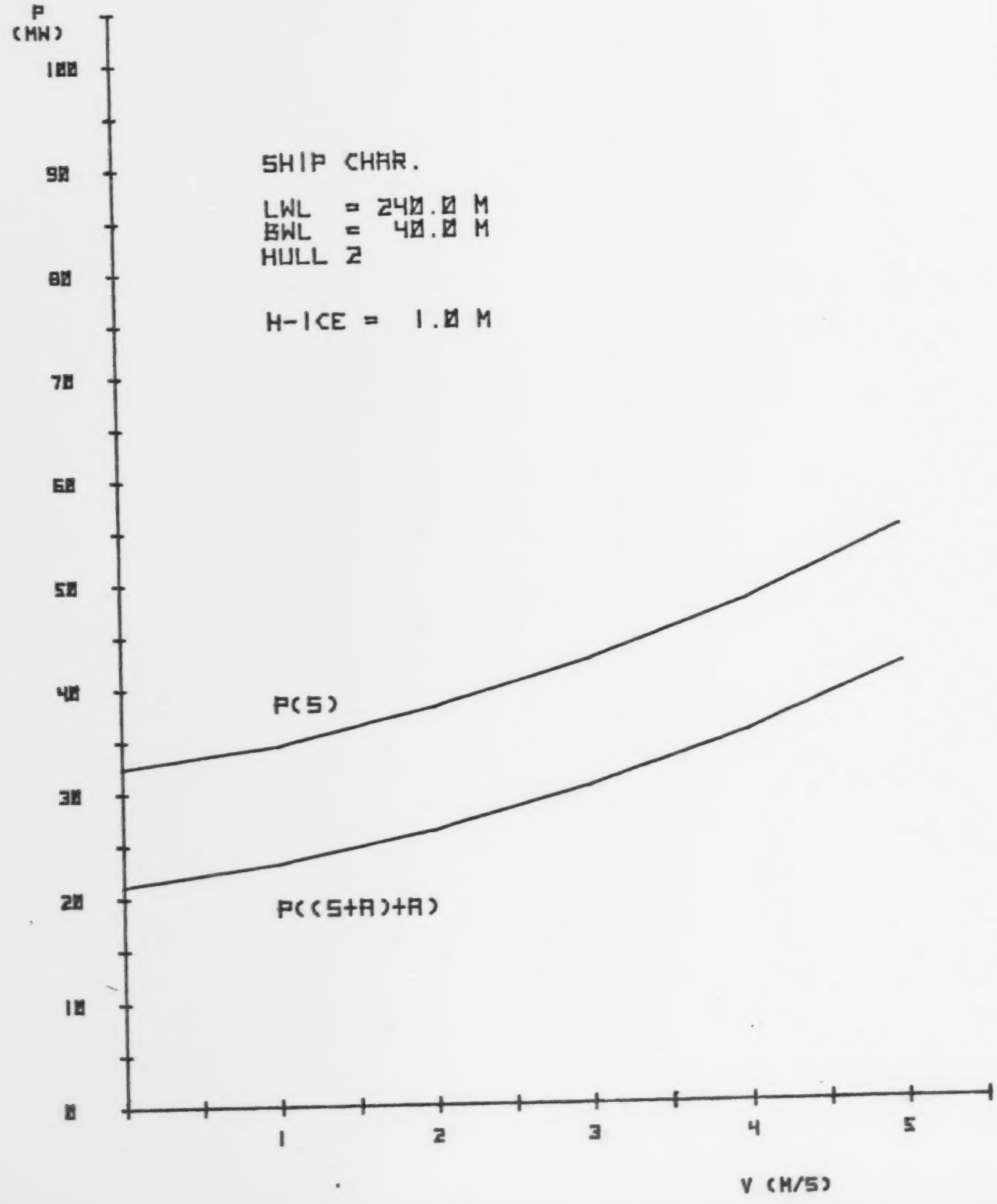
WADAM	ACIB-STUDY	FIG. 30
	POWER AS FUNCTION OF SPEED	



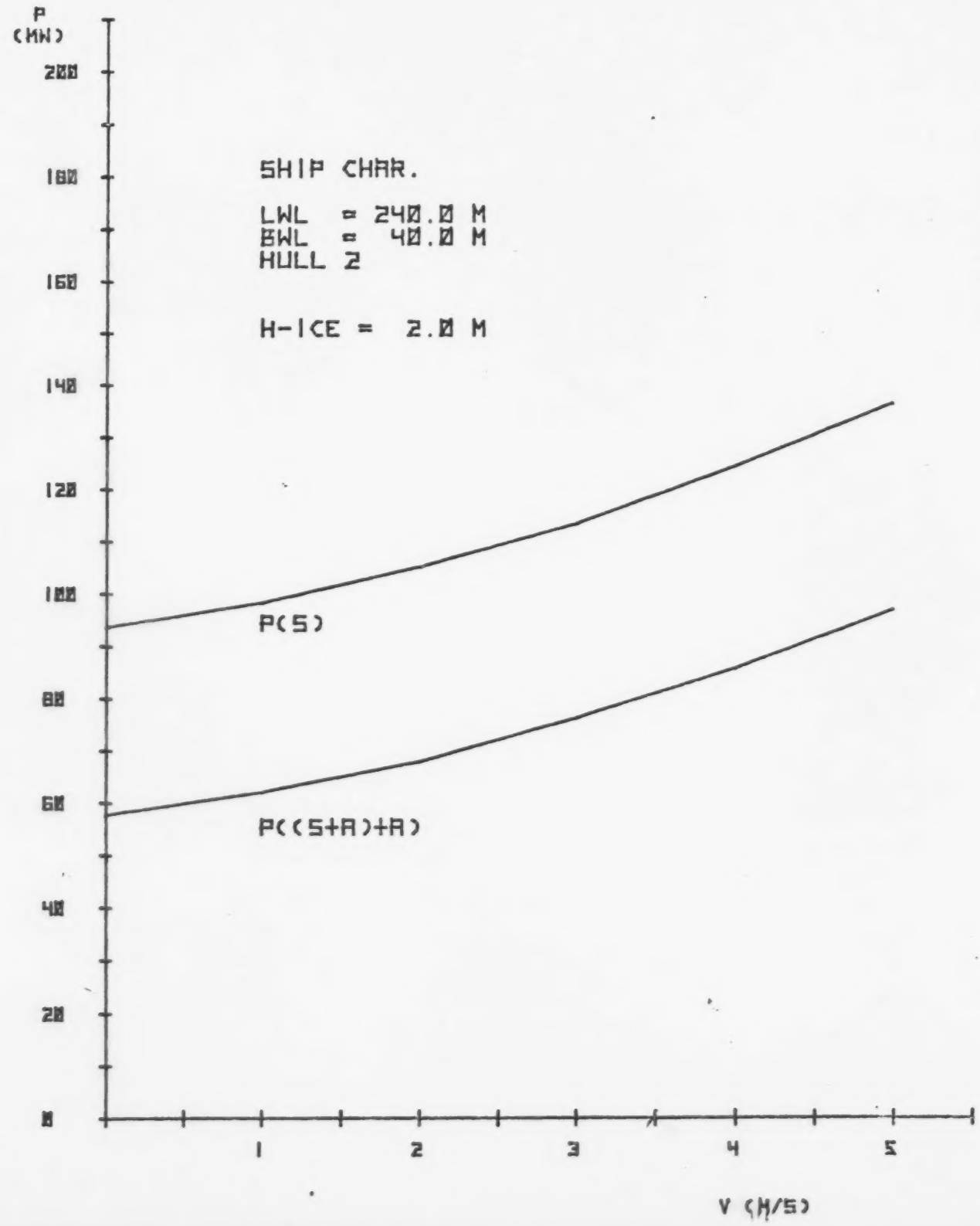
WADAM	ACIB-STUDY	FIG. 31
	POWER AS FUNCTION OF SPEED	



WADAM	ACIB-STUDY	FIG. 32
	POWER AS FUNCTION OF SPEED	



WADAM	RCIB--STUDY	FIG. 33
	POWER AS FUNCTION OF SPEED	



WADAM	ACIB-STUDY	FIG. 34
	POWER AS FUNCTION OF SPEED